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Technical Report

CHARACTERISTICS OF CORAL MORTARS

U. S. NAVAL CIVIL ENGINEERING LABORATORY

Port Hueneme, California

OBJECT OF TASK

To determine the physical properties of portland cement mortars that incorporate coral sands.

ABSTRACT

With the view of developing technical guides needed for producing coral mortar of better quality than heretofore available in field construction, certain physical properties of laboratory mortars fabricated with coralline materials were observed in a comprehensive program of tests. Nearly 2500 specimens were involved in the experimentation. To determine how and to what degree the physical characteristics of coral mortars are affected by physical factors, selected correlations were studied. Interpretation of the resultant relationships led to general formulations that serve to indicate the interdependence of mortar strength, elasticity, bulk density, volume change, weight change, air content, yield, and flow. Also included are discussions pertaining to: (1) general properties of plastic-state mortars, (2) the use of sea, brackish, or distilled water in the mix, (3) the influence of sand physical characteristics, and (4) mortar mix proportions. The test results are given in tabular and graphical form.

Of the 36 principal findings, those of paramount significance are: (1) coral mortar yield is independent of sand derivation and type of mixing water, (2) coral mortars produced with reef sand and brackish water demonstrate the least volume change, (3) the type of water employed in the mix has no practical effect upon the dynamic elastic modulus of the mortar, and (4) the nominal compressive strength of coral mortar is affected insignificantly by changing the derivation of natural-graded coral sand and increases with age irrespective of type of water used in the mix.

PREFACE

The original concept for Research Task Y-R 007-05-007, as authorized by the Bureau of Yards and Docks, provided for a series of three schedules of investigation identifiable as: Group A, designed to investigate coral as an aggregate in portland cement mortars and concretes; Group B, designed to determine the physical properties of mortars incorporating coral sands; and Group C, designed to investigate coral concrete. The Group A Schedule (coral aggregate) was reported in Technical Note N-335A; the Group B Schedule (coral mortar) is presented in this publication. Due to a decision by the Bureau of Yards and Docks to conclude Research Task Y-R 007-05-007 at the end of fiscal year 1959, the Group C Schedule (coral concrete) has been eliminated from the research program envisioned originally.

CONTENTS

CONTENTS (Cont'd)

CONTENTS (Cont'd)

CONTENTS (Cont'd)

ILLUSTRATIONS

CONTENTS (Cont'd)

CONTENTS (Cont'd)

CONTENTS (Cont'd)

CONTENTS (Cont'd)

CONTENTS (Cont'd)

INTRODUCTION

FUNDAMENTAL FACTORS

The classification of mortar depends upon the type of cementing material used (e. g., hydraulic mortar, bituminous mortar, thermoplastic mortar, lime mortar, or plaster mortar which is known also as gypsum mortar). As portland cement is employed more extensively than other cements, the terms "mortar" and "concrete" ordinarily refer to portland cement mortar and portland cement concrete, respectively. Throughout this report all reference to mortar implies a mixture of sand, portland cement, and water; all mix proportions are by weight.

The following characteristics are important in selecting mortar ingredients and their proportions relative to the ensuing mixture: workability, strength, density, and durability. These characteristics are related to the following variables: (1) derivation, gradation, and quantity of the sand, (2) cement content, (3) ratio of sand to cement, (4) water-cement ratio, (5) mixing of the ingredients, (6) placing of the plastic mortar, (7) care exercised in avoiding disturbance during set, and (8) presence of moisture while curing. These enumerated variables are interrelated intimately and each exerts considerable influence upon the others insofar as workability, strength, density, and durability are concerned. The quality required is dictated by the contemplated structural use of the mortar.

The workability of mortar is affected greatly by the sand gradation. Generally, a gradation that ranges from fairly coarse to fairly fine is more desirable than one that is uniformly coarse or uniformly fine because the former type of gradation assures a minimum percentage of voids in the mortar. This principle is significant especially with regard to the mortar in a mixture of concrete. A workable mortar should have good consistency and cohesiveness*; these features normally accompany the requisite durability and are related to development of sufficient resistance to compressive, tensile, and shear stresses. In performing the flow test the mortar is subject to only vertical force which is sufficient to initiate flow of the plastic mass; the percentage of flow thus is a measure of the shear resistance demonstrated by the mortar sample. The fact that two mortars may have identical consistencies is no guarantee that they possess equal workability. A plastic mortar of good consistency and cohesiveness at first will appear oversanded but when subjected to manipulation with the finishing trowel the resultant surface will be transformed so as to be smooth-textured.

The strength of a mortar varies with the physical characteristics and quantities of its components. In masonry structures mortar normally is subject only to compression but at times (e.g., during earthquakes, explosions, or hurricanes) it might

*Consistency indicates degree of wetness, the measure of which constitutes the flow test. Cohesiveness is the resistance to segregation produced by excessive water in a rich mix.

be subjected to tensile and shear stresses. Any mortar intended for use under adverse stress conditions must demonstrate strength values equal at least to the reference mortar incorporating Ottawa sand, all other factors such as mix proportions and flow being equal. A fallacious method of ascertaining the value of a sand for ultimate use as a concrete aggregate is to test the mortar fabricated with such sand for strength performance, in comparison with Ottawa sand mortar, and to presume that the observed characteristics and performance are applicable directly to a concrete mix incorporating that type of mortar. The strength of a mortar, unfortunately, is no criterion of the strength of the concrete incorporating such mortar, all other things being equal; the consistencies common with mortars are incommensurable with the consistencies required in concretes.

The density of a hardened mortar, which displayed good workability in the plastic state, is a function of the cement paste and of the interstices among the sand particles. The optimum condition obviously is to have these interstices well filled with cement paste. A large amount of cement paste tends to lessen the permeability, but simultaneously tends to increase the shrinkage of the mortar; the latter feature is evidenced in the shrinkage cracking which nearly always is associated with high cement content. Selecting a sand gradation that assures the minimum percentage of voids is the means of attaining a high percentage of solid or absolute volume of sand in the mortar. The optimum sand gradation will ensure the least volume of mortar possessing proper workability when the sand is combined (in the specified sand-cement ratio) with the cement paste of proper water-cement ratio. Producing mortars of equal consistencies is a function of cement paste; a coarse sand will require less paste and a fine sand, more paste. The coarse-sand mortar will have greater bulk density than the fine-sand mortar, but the use of a sand gradation that would be equivalent to combining the coarse and fine sands would result normally in a mortar better in all respects than either the coarse- or fine-sand mortars alone. The voids[1] throughout the mortar also are the result of any water which is unnecessary for cement hydration and any air which is either entrained or entrapped.

Durability embraces the following properties: impermeability, weathering resistance or ability to withstand cycles of alternate wetting and drying (and sometimes also freezing and thawing), resistance to disintegration by sulfate-bearing water, minimum shrinkage or swelling caused by ambient moisture change, minimum contraction or expansion resulting from thermal change, and resistance to impact and abrasion. Concerning impermeability, it is important to note that permeability is an indication of the continuity and size of the pores permeating the mass of mortar; as a general rule, mortar permeability primarily is a function of the water-cement ratio.

Of equal importance to these fundamental factors are the proportions in which the ingredients are combined. If the mortar incorporates a large amount of fine sand particles the excessive water required to attain the desired consistency will create more voids (as the result of water gain and subsequent partial evaporation thereof) that in turn facilitate shrinkage cracks.

PURPOSE OF INVESTIGATION

One of the objectives of the coral concrete research project is to develop criteria for expressing the general physical characteristics, and their interrelationship, of mortars fabricated with coral sands from the Pacific Ocean tropical area. This report is concerned with that objective specifically. The author has pointed out[2] the phases comprising the entire project and how accomplishment of the objectives is related to adaptation of the laboratory research results to problems in the field; included are information concerning the origin of this project, the three schedules of experimentation, the sources of coral aggregate employed, and miscellaneous factual data regarding the over-all aspects of the work.

As shown previously[2], wide variations occur in the characteristics of coral aggregates; the only qualities common to all appear to be marine origin, basic color, and mineralogical content. Obviously, variations in physical aspects would be reflected in the physical properties of mortars and concretes that incorporate coralline materials. To establish mix design data for coral concrete requires a prior foundation of facts concerning coral mortar variables and their correlation with certain parameters; this entails comparative studies of controlled variables (e.g., water-cement ratio, cement content, type of mixing water, workability, and type of coral sand) versus physical characteristics (e.g., strength and elastic properties). The Group B Schedule of experimentation serves to establish data for use in determining the basic relationships among certain factors that constitute a good coral mortar.

Part I. DESCRIPTION

Chapter 1

TECHNIQUE OF APPROACH

1. VARIABLES INVOLVED

Study of the Group B Schedule of tests indicates that 30 principal factors are common to any of the mortars investigated in this program. The mortars, to which these factors apply at five test ages, involve 13 sources of coral fine aggregate and two reference sands. The 30 factors, all of which are identified as follows, are separated into three categories:

Category	Factor	Symbol[1.1*]	
Sand: (13)	geographical source (location)[1.2]	---	
	geological source (derivation)[1.3]	R, B, P, Q	
	unit weight (bulk density)	UNW	
	voids (rodded condition)	---	
	gradation (natural or ideal) expressed as fineness modulus	FM	
	bulk specific gravity (SSD or OD basis)[1.4]; 24-hr absorption (SSD or OD basis)	SGA	
	confined crushing strength	CCS	
	Los Angeles abrasion resistance[1.5]	LAA	
	surface texture; particle shape; physical condition — petrographical analysis	PET	
	coefficient of thermal linear expansion	α	
Water: (3)	distilled	---	
	brackish	---	
	sea	---	
Mortar: (14)	water content	---	Plastic state
	cement content	CMC	Plastic state
	water-cement ratio	W/C	Plastic state
	aggregate-cement ratio	A/C	Plastic state
	flow	---	Plastic state
	yield	---	Plastic state
	unit weight	UWP	Plastic state
	entrained air content	EAC	Plastic state

*Decimal notations appear as notes at the end of each chapter. Whole numbers refer to bibliographical information which appears at the end of the report.

volume change from plastic to solid state	VCH	
weight change from plastic to solid state	WCH	
bulk density	BUD	Solid state
dynamic elastic modulus	DYE	
flexural strength (rupture modulus)	FLS	
compressive strength of modified cubes	MCS	

The possible combinations of these 30 items taken two at a time, and disregarding the order in which the combinations are made, is equal to $(30!) \div (2!)\,(30-2)!$, or a total of 435. Similarly, the combinations possible when taken three at a time (e.g., water type versus W/C versus MCS) amount to 5560. Considering the practical purposes of the project, it is evident that an arbitrary determination of the most likely or promising combinations is necessary.

2. ANALYTICAL RELATIONSHIPS

To determine the physical properties of mortars incorporating coral sands, the prime relationships must be established between coral fine aggregate and coral mortar, in the plastic state as well as in the hardened or solid state. To clarify the statement in Section 1 relative to arbitrary determination of combinations, the relationships listed in Table I result from careful screening of the combinations possible; the screened relationships were checked for possible correlation with the insignificant factors revealed in the Group A Schedule[2] and the list was shortened accordingly (e.g., Table I omits all relationships involving the effect of a upon the physical properties of coralline sand mortars). The relationships as listed are considered potentially valuable in any adaptation of laboratory findings to coral mortar problems at the construction site.

In the Table I presentation all of the 78 indicated correlations of variables apply equally well, in principle, to each sand source. For those sands in short supply, however, it was possible to establish only a few of the relationships shown. The eight correlations[1.6] which involve petrographical aspects of coral sands are insignificant and thus it was impractical to evaluate them. The establishment of two correlations involving absorption of coral fine aggregate, as listed in Group 2 of Table I, was not appropriate because average absorption values for the various sands[1.7] were considered fixed. The nine correlations involving fineness modulus of the sands, as listed in Groups 1, 2, 6, 7, and 8 of Table I, were not established because the FM value for each sand was considered fixed for the particular gradation category involved; had it been feasible to fabricate various blends of gradation, such FM correlations might

Table I. Relationships Among Principal Factors Common to Coral Mortars

Group	Principal Factors			Possible Correlations
1	a. water type b. sand FM c. sand voids d. sand PET* e. mortar EAC	versus	a'. mortar UWP	5
2	a. water type b. sand FM* c. sand voids d. sand PET* e. sand SGA* f. mortar CMC** g. mortar W/C h. mortar A/C** i. mortar EAC	versus	a'. mortar flow b'. mortar yield	18
3	a. sand UNW	versus	a'. mortar EAC b'. mortar UWP	2
4	a. mortar W/C	versus	a'. mortar EAC	1
5	a. sand voids b. mortar W/C	versus	a'. mortar BUD***	2
6	a. water type b. sand FM* c. mortar EAC	versus	a'. mortar BUD***	3
7	a. water type b. sand FM* c. sand voids* d. sand PET* e. mortar W/C f. mortar EAC	versus	a'. mortar VCH*** b'. mortar WCH***	12
8	a. water type b. sand RBPQ c. sand voids d. sand FM* e. sand CCS f. sand PET* g. mortar W/C h. mortar A/C i. mortar flow j. mortar EAC	versus	a'. mortar DYE**** b'. mortar FLS**** c'. mortar MCS****	30
9	a. mortar BUD**** b. mortar FLS****	versus	a'. mortar DYE**** b'. mortar FLS**** c'. mortar MCS****	5

* Correlativity is insignificant; refer to Section 2.
** Correlation with mortar flow is impossible; refer to Section 18.
*** At ages 1, 7, 28, 91, and 364 days.
**** At ages 7, 28, 91, and 364 days.

have been realized. The two correlations involving the sand voids factor, as listed in Group 7 of Table I, were not established because there are insufficient VCH and WCH data to correspond with variously derived coral sands.

Length of mixing time was omitted, although planned originally, because inclusion of this factor would have extended the laboratory work considerably beyond the deadlines established for the Group B Schedule of tests. Organic content, chlorides present, and cleanliness (washed versus nonwashed condition) were not considered of sufficient importance, in view of the information developed in the Group A Schedule of tests, to warrant inclusion among the principal factors although these three factors normally influence the physical properties of coral mortar and coral concrete.

The 30 principal factors enumerated previously represent dependent and independent variables. These may be respectively either controlled physical variables that indicate mortar ingredient values or parameters that are recognized as physical characteristics of the resultant mortars in the plastic state and in the solid state. The dependent variables are expressible through functions characterized by each value of the parameters; thus are derived the coordinates of the loci which reflect the numerous correlations presented in Table I and that comprise the graphs in Part II. Every value of any one of the accepted parameters theoretically relates to one or more particular values of any preselected dependent variable. In essence, this study attempts to reveal those relationships with regard to coral mortars.

CHAPTER 1 END NOTES

1.1 Utilization of this alphabetical system to the maximum extent possible is the most effective means of minimizing lengthy terminology and awkward technically descriptive phrases.

1.2 Refer to Table II.

1.3 Refer to second paragraph of Section 3.

1.4 SSD signifies saturated-surface-dry condition and OD signifies oven-dry condition.

1.5 Applicable only to coarse portions of type coarse-fine aggregates.

1.6 These appear in Table I as Correlations 1d-a', 2d-a', 2d-b', 7d-a', 7d-b', 8f-a', 8f-b', and 8f-c'.

1.7 Listed in Tables V, VIA, and XI of Reference 2.

Chapter 2

MATERIALS

3. FINE AGGREGATES

The coral aggregates investigated came from geographical locations that were under USN operational control at the time of procurement and may be considered as representative of some of the distinct coral sources found in the Pacific Ocean area.

An alphabetical code is used to assure easy identification of aggregates, the sources of which require considerable description, and to readily signify the characteristics of aggregates (Group A Schedule) and mortars (Group B Schedule). The list shown in Table II indicates geographical location but not geological source. Each coral aggregate is distinguished as to derivation or geological source by a capital letter that follows the underlined geographical symbol. Reef coral is designated by the letter R, beach material by B, bank-run coral by P, and quarry coral by Q. The letter C immediately precedes the derivation symbol if the aggregate was subjected to crushing operations after extraction from its natural state. The type of coral aggregate refers to general size which is designated by lower-case letters; the letter c denotes coarse, the letter f fine, and cf denotes combined coarse-fine. The Arabic number following the lower-case letter c indicates the maximum size of particle in terms of hundredths of an inch (e.g., KWCRc37 signifies coarse aggregate, consisting of reef coral dredged and crushed at Kwajalein, and having a maximum size of particle not greater than 3/8 in. or 0.375 in.).

Fifteen sands were employed in carrying out the Group B Schedule

AMBf	ENQcf	KWCRc37
BJBf	ENRcf	NNQf
CLQf	FDQf	OO
ENCRcf	GMRf	PTQf
ENPcf	HMPf	SS

Of the coral fine aggregates received, over half were limited to 300-lb quantities; these scarce sands were CLQf, FDQf, HMPf, NNQf, and PTQf. It was impracticable to include the fine portions of JNCRcf and MAQcf, each of which was available in 300-lb quantities, because each was mainly coarse material. To conserve aggregates for later use in the contemplated Group C Schedule, the mortar experiments consequently were confined to the thirteen

Table II. Aggregate Source Identification Symbols

Geographical Symbol	Geographical Location
AM	Amon Islet, Eniwetok Atoll, Marshall Islands
BJ	Biijiri Islet, Eniwetok Atoll, Marshall Islands
CL	Cabras Island, Guam, Marianas
EN	Eniwetok Islet, Eniwetok Atoll, Marshall Islands
FD	Fadian Point, Guam, Marianas
GG	San Gabriel River Wash gravel, Irwindale, Los Angeles County, California
GM	Apra Harbor, Guam, Marianas
HM	Harmon USAF Base, Guam, Marianas
JN	USAF Base, Johnston Island
KW	Harbor, Kwajalein Atoll, Marshall Islands
MA	Com Nav Marianas, Guam, Marianas
NN	Naval Hospital, Guam, Marianas
OO	Fox River sand, Ottawa, LaSalle County, Illinois
PT	Pati Point, Guam, Marianas
SS	San Gabriel River Wash sand, Irwindale, Los Angeles County, California

coral and two reference sands tabulated above. As the relatively large quantities represented only three principal coral sand sources (i.e., 10,000 lb each of AMBf and BJBf, 24,000 lb of GMRf, and 1700 lb of KWCRc37), it became apparent that the ultimate scope of the mortar program would be restricted. An optimum set of nine (or a minimum of six) test specimens, to correspond to each of the controlled variables that would be applicable to each of the available sands, would have been desirable for developing comprehensive data; but to have done so would have reduced critically the quantities of materials reserved for later use.

Nine of the thirteen coral sands[2.1] were used as natural-graded[2.2] materials in the Group B Schedule of tests. One of these nine coral sands (GMRf which was in plentiful supply), one reference sand (SS), and four of the six available Eniwetok Atoll sands were reblended separately to conform to Weymouth's ideal gradation curve. Consequently, at least twelve more complete series of mortar mixes would be necessary before the Group B Schedule should be considered exhausted. Such complementary data could bear some importance relative to interpretation of the test data reported herein.

Each of the thirteen coral sands and the two reference sands had been packaged in units of about 5000 gm; these nominal amounts, packaged in paper sacks, had been stored in the Laboratory since August 1954. Room air temperatures during storage varied from 55 to 85 F and average relative humidity during this interim ranged between 35 and 55 percent.

Sampling of all coral sands had been accomplished as part of the Group A Schedule of tests.[2] No coral sands had been laboratory-washed. Drying of coral sand (when necessary) preparatory to sampling and packaging operations had been done by exposure, while spread upon the dry concrete deck of the Laboratory, under warm ambient conditions; use of the oil-fired rotary dryer was infeasible as the minimum temperature attainable was about 900 F, a level that destroys the natural aspects of coralline materials inasmuch as the $CaCO_3$ is converted into CaO. The reference sand SS, however, had been washed and graded, in conformity with 1954 California State Highway Division standard specifications for portland cement concrete, prior to commercial delivery to outdoor bins at the Laboratory; subsequently all SS aggregate has been passed through the rotary dryer and cooled to room temperature prior to packaging.

4. PORTLAND CEMENT

All portland cement used throughout the coral mortar research project was BEAR brand produced at the Oro Grande Division of the Riverside Cement Company near Victorville, California. This cement, manufactured as a Type I portland cement, conformed to ASTM Designation C150-53 and to Federal Specification SS-C-192a. Information pertinent to the chemical and physical properties of the cement is found in Table III. The cement, received 22 April 1955 in standard domestic-type paper sacks directly from the mill, was placed in 55-gal air-tight steel drums as a precautionary measure against partial absorption of ambient moisture while stored in the Laboratory. The average temperature range of the storage-room air extended from 40 to 90 F.

5. MIXING WATER

Initially, all sea water was obtained from the Pacific Ocean surface at a location 0.5 mile offshore from Silver Strand Beach, which is situated immediately west of Port Hueneme harbor. Several months after inauguration of the Group B Schedule, sea water of equivalent quality was obtained regularly from a 65-ft deep well located at the Laboratory about 200 ft inland from the ocean; the average temperature at discharge was 61 F. The salinities of the two sources of sea water used during July 1955 were as follows:

Source	Salinity, °/oo (a)	Salinity, °/oo (b)
Offshore	31.35	33.1
Deep well	31.32	33.0

Note: (a) By chemical analysis.
(b) By specific gravity measurements.

Salinity, defined in Reference 3, is expressed in parts per thousand and the ratio is signified by the symbol °/oo. Salinity of sea water generally is between 33 and 37 °/oo, values obtained conveniently as hydrometer measurements modified by conversion factors.[4,5] It is of interest to compare the temperatures, densities, and salinities of sea water at certain islands and coral atolls in the Pacific Ocean tropical area and at Port Hueneme; Table IV reveals that the differences are slight except with regard to average temperature.

The specific gravity of distilled water for convenience was assumed to be 1.000 at 23 C (73.4 F) rather than 0.998, which is the true value at that temperature. The specific gravity of the sea water was not considered equal to

Table III. Properties* of Portland Cement Used in Mortar Mixes

CHEMICAL (percentages by weight)	
Silica (SiO_2)	21.0
Alumina (Al_2O_3)	4.7
Iron Oxide (Fe_2O_3)	3.3
Magnesium Oxide (MgO)	4.8
Sulfur Trioxide (SO_3)	2.2
Ignition Loss	1.8
Insoluble Residue	0.13
Tricalcium Aluminate ($3CaO \cdot Al_2O_3$)	6.9
Tricalcium Silicate ($3CaO \cdot SiO_2$)	47.0
PHYSICAL	
Specific Gravity (LeChatelier flask)	3.12
Specific Surface (Blaine air permeability)	3450 sq cm/gm
Initial Set (Gillmore needle)	160 minutes
Final Set (Gillmore needle)	310 minutes
Soundness (length increase due to autoclaving)	0.28
Tensile Strength (standard 00 mortar briquets) at:	
age 3 days	300 psi
age 7 days	360 psi
Compressive Strength (graded 00 mortar cubes) at:	
age 3 days	1670 psi
age 7 days	2450 psi

*Certified 20 April 1955 by Chief Chemist of Oro Grande Division of the Riverside Cement Company. Specific Gravity value shown is average of several determinations made in May 1955 at NCEL Materials Division.

Table IV. Principal Properties of Pacific Ocean Water for Use in Coral Mortars and Concretes

Geographical Location	Surface Temperature, F			*Surface Density			Surface Salinity, $^o/oo$			Calendar Period of Observations
	approx min	mean annual	approx max	approx min	mean annual	approx max	approx min	mean annual	approx max	
Eniwetok	**76.	83.	**88.	**1.018	1.0220	**1.024	**31.	34.5	**36.	at random
Guam	80.	83.	88.	1.0188	1.0218	1.0234	31.1	34.5	36.2	1949-1951
Johnston	72.	79.	84.	1.0221	1.0231	1.0270	33.8	35.1	37.0	1947-1951
Kwajalein	76.	83.	90.	1.0234	1.0220	1.0263	31.6	34.5	36.7	1949-1951
Port Hueneme	50.	58.	72.	**1.023	1.0249	**1.027	**29.	33.5	**35.	1919-1951

* Actually specific gravity of sea water at the surface.
** Estimated by Hydrographic Office on basis of data from analogous areas.

References: (a) USN H. O. Washington ltr ser 7180 of 22 Aug 1955 to NCEL.
(b) USC&GS Special Publications 280 (Surface Water Temperatures, Pacific Ocean, 1948) and 281 (Sea Water Density, Pacific Ocean, 1950).

1.025, the mean annual surface value corresponding to the mean annual surface temperature of 58 F shown in Table IV for Port Hueneme, but was assumed to be 1.023, which value was equivalent to the estimated minimum specific gravity of surface sea water at this location; the 1.023 value was considered a more probable figure in view of the salinity measured by chemical analysis and since nearly all of the sea water used in the mixes had emanated from the Laboratory deep well.

Treated fresh water was drawn from the cold tap-water system supplied by deep wells situated at the Naval Construction Battalion Center. Throughout the Group B Schedule of experiments the mean temperature of the piped fresh water ranged from 64 to 70 F upon discharge at the cold tap. A zeolite water-softening system reduced the hardness of the raw water from about 25 to about 10 grains per gallon. An analysis of typical raw water employed during the years 1955 and 1956 would have indicated the following average orders of magnitude:

total hardness[2.3]	= 410 ppm[2.4]
bicarbonate alkalinity or $Ca(HCO_3)_2$	= 190 ppm[2.5]
chlorides	= 40 ppm
total dissolved solids	= 780 ppm
pH value	= 7.7 ± 0.3

Brackish water was prepared manually by combining piped fresh cold water with bottled sea water; the ratio of proportions (by volume) was 5 parts of fresh to 1 part of sea water. The specific gravity of such manufactured brackish water was calculated as 1.003[2.6], a value that was correct also at 75 F, which was the average air temperature in the mortar-mixing room. Glass bottles, of 5-gal capacity and fitted with cork stoppers, were the means of storing sea water and brackish water in the mortar-mixing room at least 96 hours before use in any mortar mixture.

Three types of water were used in the mortar experiments; namely, distilled, brackish, and sea water. All water was introduced into the mixes at a temperature of 75 ± 2 F. Work Sheet WRL-3 in Appendix III exemplifies a typical application of specific gravity values incident to computations for percentage of entrained air in mortars fabricated with the various types of water. Because of the scarcity of certain coral sands, those coral mortars that involved sea water or brackish water incorporated only natural-graded sands, as shown in Table V.

Table V. Identification of Sands and Water Used in Mortar Mixes

Aggregate		Prism	Water	Quantity of Mixes Corresponding to W/C, by wt					Σ
Identification	Gradation	Compaction	Type	0.3	0.4	0.5	0.7	0.9	
AMBf	N	H	D	4	5	5	5	9	28
AMBf	N	H	B	4	4	4	4	4	20
AMBf	N	V	B	4	--	--	--	--	4
AMBf	N	H	S	4	4	4	4	4	20
Σ	--	--	--	16	13	13	13	17	72
BJBf	N	H	D	13	16	10	12	14	65
BJBf	N	V	D	2	4	4	4	3	17
BJBf	N	*V	D	--	--	1	1	1	3
BJBf	N	H	B	4	6	5	3	5	23
BJBf	N	H	S	6	3	3	7	3	22
Σ	--	--	--	25	29	23	27	26	130
CLQf	N	H	D	--	2	5	2	--	9
ENPcf	N	H	D	--	--	4	--	--	4
ENPcf	W	H	D	--	--	5	--	--	5
ENQcf	W	H	D	--	--	5	--	--	5
ENRcf	W	H	D	--	--	5	--	--	5
ENCRcf	W	H	D	--	--	4	--	--	4
Σ	--	--	--	--	--	23	--	--	23
FDQf	N	H	D	--	5	6	5	--	16
GMRf	N	H	D	7	5	6	5	6	29
GMRf	W	H	D	--	6	9	7	--	22
GMRf	N	H	B	3	4	5	6	2	20
GMRf	N	*V	B	--	--	1	--	--	1
GMRf	N	H	S	5	3	5	3	3	19
GMRf	N	*V	S	2	--	1	--	--	3
Σ	--	--	--	17	18	27	21	11	94
HMPf	N	H	D	--	6	6	4	--	16
JNCRcf	N	excluded because of extreme coarseness							--
[illegible]	N	H	D	--	5	5	5	--	15

ENQcf	W	H	D	--	--	5	--	--	5
ENRcf	W	H	D	--	--	5	--	--	5
ENCRcf	W	H	D	--	--	4	--	--	4
Σ	--	--	--	--	--	23	--	--	23
FDQf	N	H	D	--	5	6	5	--	16
GMRf	N	H	D	7	5	6	5	6	29
GMRf	W	H	D	--	6	9	7	--	22
GMRf	N	H	B	3	4	5	6	2	20
GMRf	N	*V	B	--	--	1	--	--	1
GMRf	N	H	S	5	3	5	3	3	19
GMRf	N	*V	S	2	--	1	--	--	3
Σ	--	--	--	17	18	27	21	11	94
HMPf	N	H	D	--	6	6	4	--	16
JNCRcf	N	excluded because of extreme coarseness							--
KWCRc37	N	H	D	--	5	5	5	--	15
MAQcf	N	excluded because of extreme coarseness							--
NNQf	N	H	D	--	4	4	--	--	8
OO	T	H	D	11	10	18	11	11	61
OO	T	H	B	5	5	5	5	5	25
OO	T	H	S	5	5	5	5	5	25
Σ	--	--	--	21	20	28	21	21	111
PTQf	N	H	D	--	--	4	4	--	8
SS	N	H	D	4	8	8	8	12	40
SS	N	V	D	--	4	4	4	4	16
SS	N	**V	D	--	--	--	--	4	4
SS	W	H	D	--	5	8	6	--	19
SS	N	H	B	--	4	4	4	4	16
SS	N	H	S	4	4	8	4	4	24
Σ	--	--	--	8	25	32	26	28	119
TOTAL Σ	--	--	--	87	127	176	128	103	621

Denotations:
B = Brackish water
D = Distilled water
H = Hand-tamped
N = Natural gradation
S = Sea water
T = ASTM Designation C109-54T
V = Vibrated at amplitude of 0.0090 in. for 2 minutes
W = Weymouth's ideal gradation
*V = Vibrated at amplitude of 0.0075 in. for 3 minutes
**V = Vibrated at amplitude of 0.0090 in. for 3 minutes

2

CHAPTER 2 END NOTES

2.1 The four derived from Eniwetok Islet were excluded and used for ideal gradation blends.

2.2 CLQf, FDQf, KWCRc37, NNQf, and PTQf were manufactured in the field by roll-crushing suitably sized portions of the respective parent materials and thus truly were manufactured sands.

2.3 Hardness in grains may be converted to ppm (parts per million) on the basis that 1 gr/gal is equivalent to 17.6 ppm.

2.4 Comprised of calcium hardness as 260 ppm of $CaCO_3$ plus magnesium hardness (determined in terms of equivalent calcium hardness) as 150 ppm of $CaCO_3$.

2.5 In terms of equivalent $CaCO_3$.

2.6 [(1/6)(sp gr sea) + (5/6) (sp gr fresh)] = [(1) (1.023) + (5) (0.99)] ÷ (6) = 1.003. Measurements made with a gravitometer, wherein ethyl-benzene is the standard of reference, indicated that the 0.999 value for fresh water was correct at all temperatures between 61 and 75 F, inclusive.

Chapter 3

MORTAR

6. SPECIMEN FABRICATION

The ambient temperature and relative humidity during fabrication of the mortar specimens were maintained, respectively, at 75 F and 57 percent or as close thereto as possible.[3.1] Excluding preliminary trials, the first mortar mix of the series proper was begun 12 May 1955 and the last was completed 14 February 1956.

All specimens fabricated were rectangular prisms* (2 in. by 2 in. by 11 in.). The program provided four prisms per water-cement ratio per type of mixing water per type of sand gradation per age at test. This arrangement permitted one prism per controlled variable for test at each age of 7, 28, 91, and 364 days. Details concerning the molds employed during specimen fabrication are presented in Section 7.

Prisms were cast in accordance with Section 9 of ASTM Designation C348-54T in those cases involving hand tamping; the same ASTM method was used for specimens compacted by vibration except that screeding was delayed until after vibration had been completed. The casting of hand-tamped coral mortar specimens is illustrated in Figures 1, 2, and 3. Vibration was accomplished by fastening the specimen gang mold to a vibrating table. Vibration frequency always was 60 cycles per second and vibration amplitudes ranged from 0.0090 in. (for 2 minutes) to 0.0075 in. (for 3 minutes). The usual amplitude throughout the series was 0.0090 in. (for 2 minutes) and the corresponding acceleration was 106.6 ft per sec per sec (3.3 g). Mortar-mix portions needed for workability and air content observations never were used in fabricating the specimens.

All mortar prisms were cured and stored in 73.4 ± 2 F air at 100-percent RH instead of in water as specified in ASTM Designations C87-52 and C109-54T. This departure from ASTM requirements was based on conclusions developed in Germany[6] to the effect that curing and storage in moist air serve to maintain shrinkage stresses at an absolute minimum. Curing of the test specimens during the first 24 ± 2 hours after fabrication, was accomplished in a moisture cabinet. At age 24 ± 2 hours each specimen was stripped of its mold, measured for bulk density, and placed in the fog room for storage until time of test.

*Refer to Section 9.

Figure 1. Tamping coral mortar into gang mold.

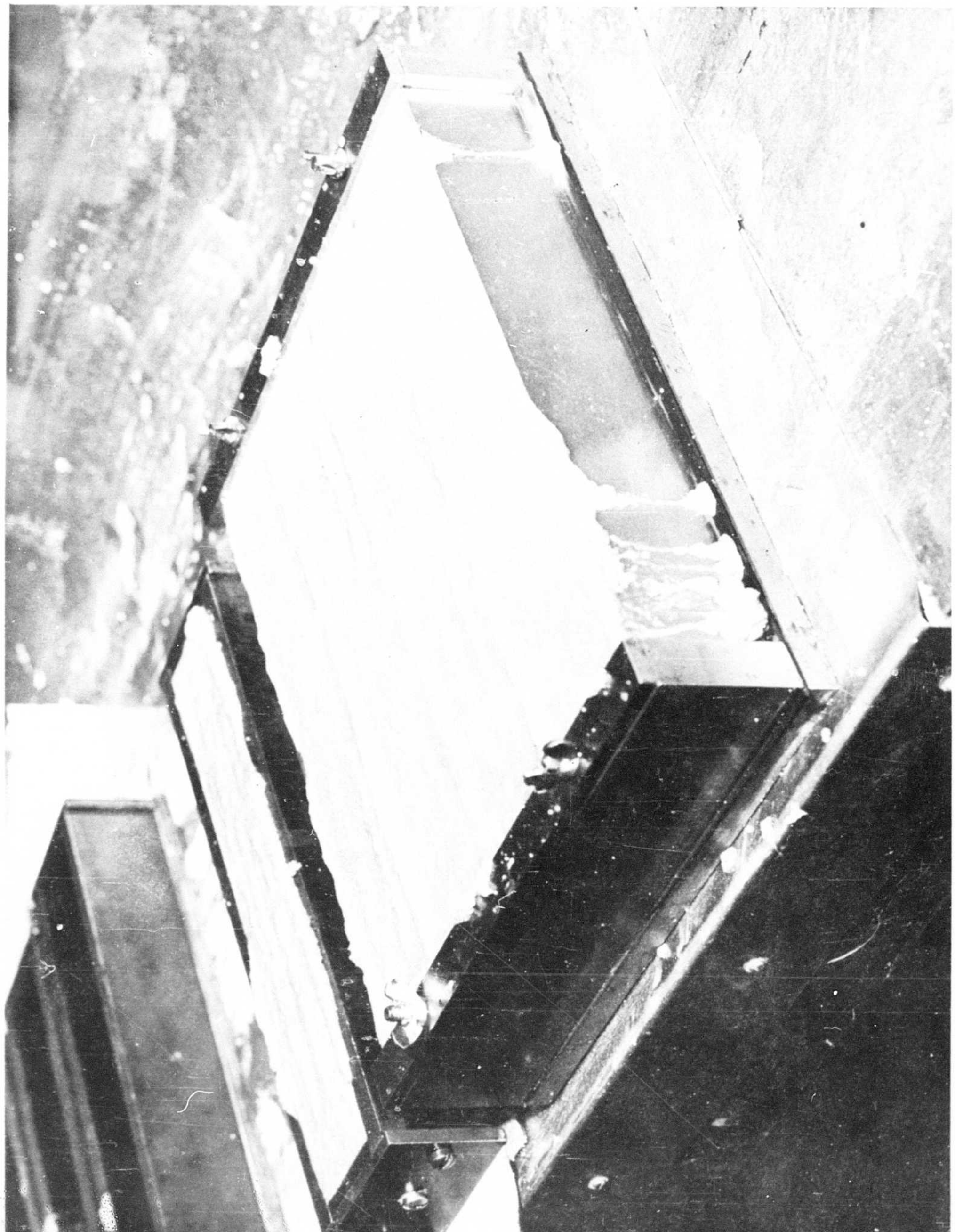


Figure 2. Coral mortar, after tamping into single mold and gang mold, prior to screeding.

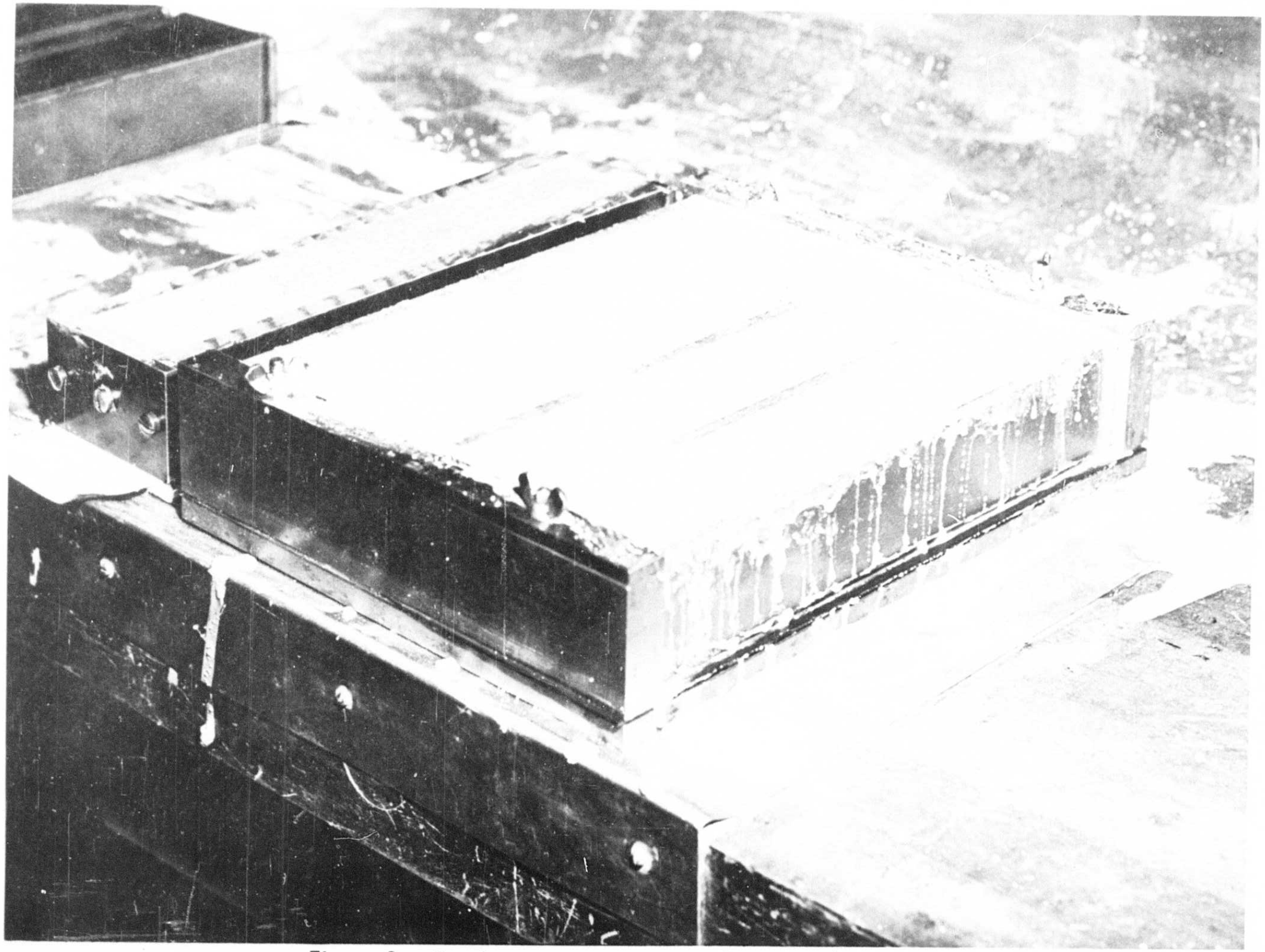


Figure 3. Coral mortar appearance after screeding.

7. SPECIMEN MOLDS

The standard commercially available steel molds for use in fabricating rectangular prisms of 2-in.-square cross section normally are of the single-specimen type. The molds must be dimensionally accurate to 0.01 inch. Exorbitant time is required to disassemble, clean, oil, and reassemble such molds. Moreover, such molds incorporate no provision against leakage at the joints; ASTM Designation C348-54T specifies a mixture of paraffin and rosin applied to the exteriors of the joints to insure watertightness. All these features were considered unsatisfactory and tedious.

During the early portion of the Group B Schedule the sixteen available single-specimen type steel molds[3.2] were used with pressure-sensitive tape[3.3] rubber-cemented to the mold base plates in such fashion that the adhesive side of the 3-in.-wide tape was in contact with the bottom edges of the mold side plates. The interiors of the molds thus assembled were well coated with low-viscosity grease and special care was taken to insure that the slots in the end plates also were well coated. When mortars having water-cement ratios of 0.7 or greater were used, the mold bottoms were lined with waxed paper to preclude bond that normally occurred (with the relatively sloppy mortars) between the prism and adhesive tape; this procedure was necessitated by the fact that grease alone would not suffice in preventing bond. Figures 4, 5, and 6 illustrate the procedures involved prior to casting specimens. Despite the improved mode of operation, this system required considerable man-hours for cleaning, assembling, greasing, and stripping of the molds; Figure 7 depicts the early phases of a typical stripping operation.

Development of a suitable four-specimen steel gang mold[3.4] was indicated and consequently two such molds were built; these proved to be watertight and required no special sealing compound as specified by ASTM. In lieu of the paraffin-rosin sealing compound, a 0.0625-in. neoprene layer was used to cover the entire base plate. The intervening sheet of neoprene also served to alleviate any bond that might have developed between the mortar prisms and the steel base plate. Table VI reveals the time-saving features of a typical four-specimen gang mold in comparison with four single-specimen molds.

8. MIXES INVESTIGATED

None of the coral sands required washing since organic content and chlorides present had been shown[2] to be insignificant. Though scheduled originally, the natural-graded coral sands were not recombined to conform to

Figure 4. Applying rubber cement to tape preliminary to assembly of single mold.

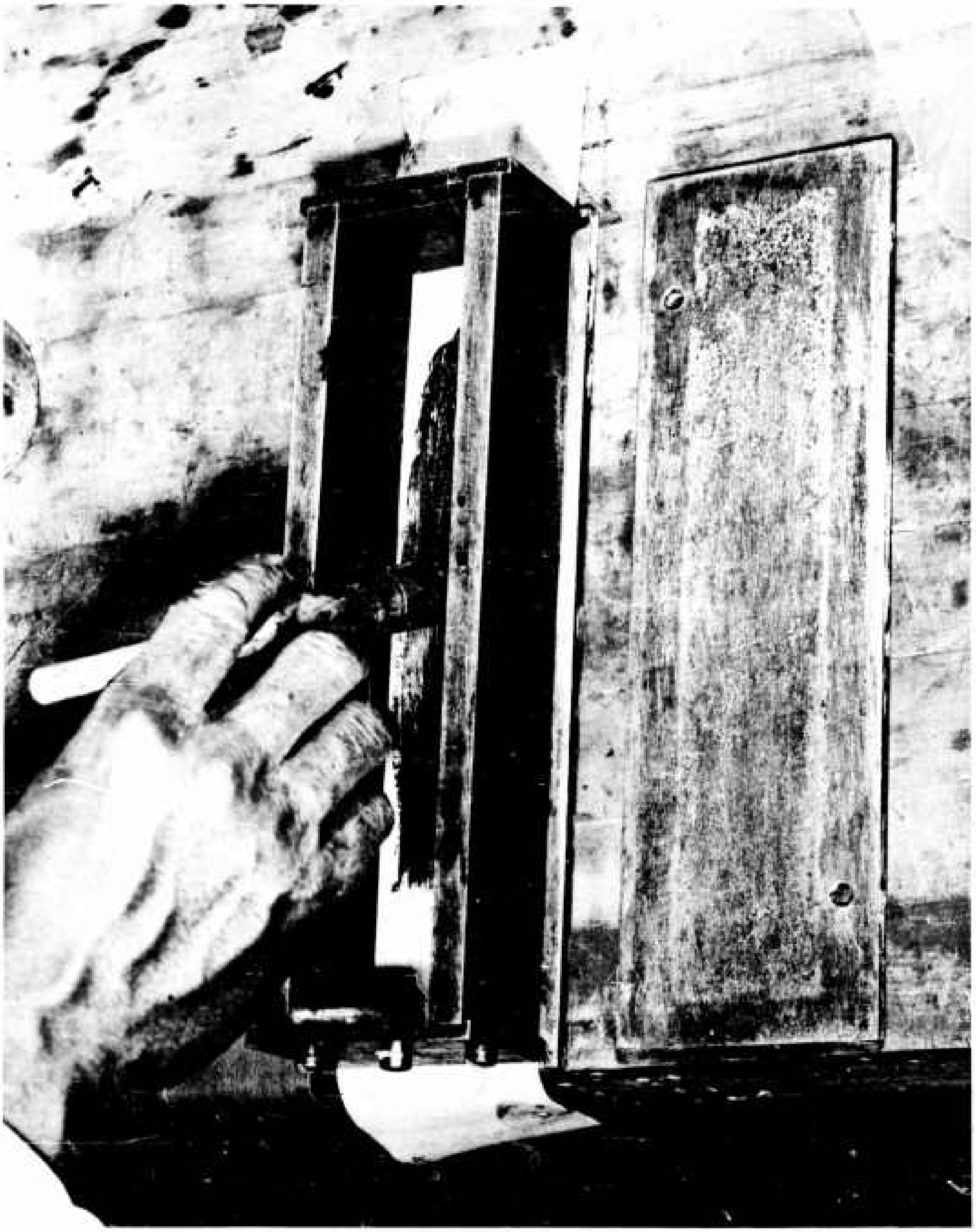


Figure 5. Greasing single mold after assembly involving tape.

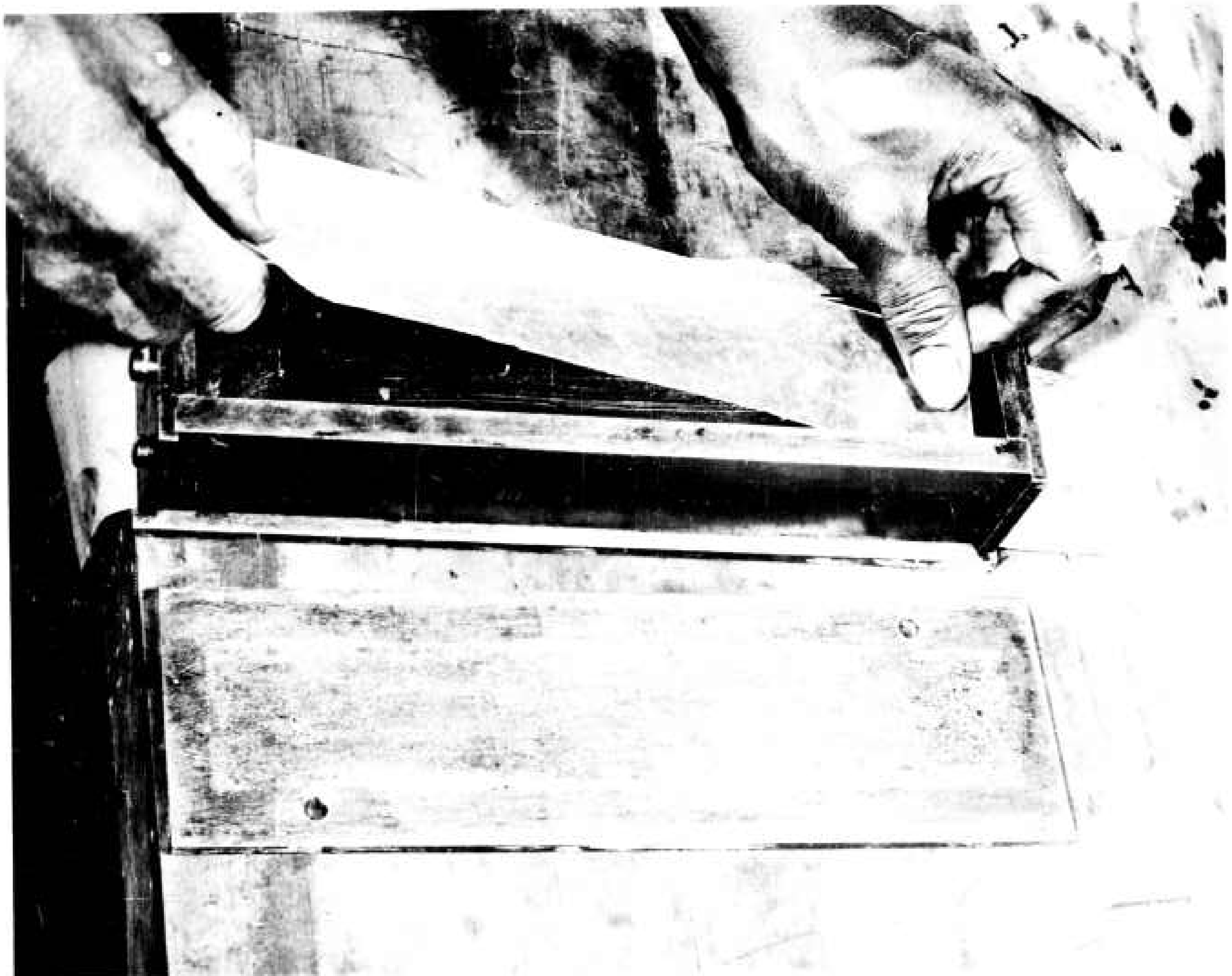


Figure 6. Installing waxed paper insert to preclude bond between mortar prism and tape.

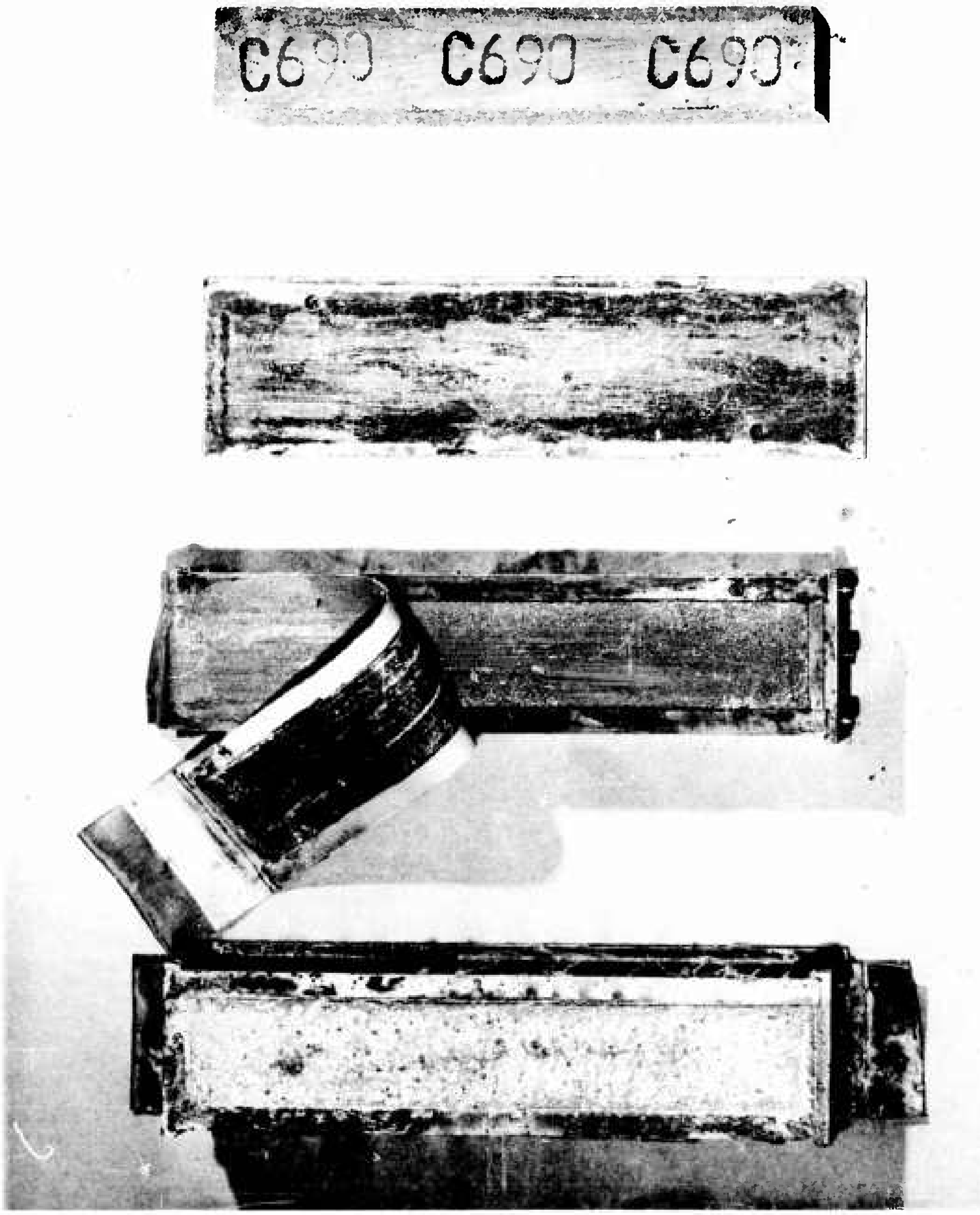


Figure 7. Procedural steps in stripping mortar prism from mold.

Table VI. Time Study of Operations with Single and Gang Molds

Type of Manual Operation	Time Consumption with Four Single Molds	Time Consumption with One Gang Mold	Time Saved by Using Gang Mold
Stripping	6 minutes	4 minutes	25 percent
Cleaning	7 minutes	4 minutes	43 percent
Assembling	14 minutes	7 minutes	50 percent
Total	27 minutes	15 minutes	44 percent

Note: (1) All times shown are averages based upon operations extending throughout six working days.

(2) Single-mold specimens each 2.00 in. by 2.00 in. by 11.19 in. and gang-mold specimens each 2.00 in. by 2.00 in. by 11.00 in.

the gradations specified in ASTM Designation C144-52T. Despite the desirability of studying coral mortars fabricated with ASTM-graded material, the scarcity of coral sands precluded such investigations; likewise, arbitrary gap-gradation was deleted from the program. As a consequence, only two classes of coral sand gradation were used; namely, natural and ideal. The Ottawa reference sand gradation, range MINUS 20 PLUS 100, conformed to ASTM Designation C109-54T. Determinations of SSD condition of the various mortar sands were accomplished as described in Reference 2. To ensure more or less constant moisture content from day to day, packaged sand samples were kept in 5-gal-capacity metallic containers equipped with metal covers.

Mortar mixing was performed as specified in ASTM Designation C305-53T, except that a Hobart Model C-10 mixer was substituted for the regular Hobart Model N-50 mixer because of the relatively large batches involved.

Air content values of the mortars were determined in accordance with ASTM Designation C185-53T but only after the flow values had been measured.

Results were obtained first with mortars incorporating BJBf, GMRf, and OO sands; the balance of the Group B Schedule then was abbreviated to be commensurate with the availability of the remaining eleven sources of coral sand. For these reasons mortars fabricated with BJBf, GMRf, and OO sands were tested at the ages of 7, 28, 91, and 364 days; all mortars that incorporated AMBf, CLQf, ENCRcf, ENPcf, ENQcf, ENRcf, FDQf, HMPf, KWCRc37, NNQf, or PTQf sands were tested at age 28 days and, dependent upon supply available, in certain cases also were tested at ages 7 and 91 days. Mortars fabricated with SS sand were tested at all four ages. The abbreviated portion of the testing program was based on the following aspects: (1) strength-age relationship, (2) water-cement ratio, and (3) distilled water.

The 28-day age was chosen as the standard to assure correlation with: (1) contemplated coral concrete test data, (2) nominal test-age shown in specifications, and (3) strength-age data previously acquired with GMRf, SS, and OO sands during the preliminary stages of the Group B Schedule.

A water-cement ratio of 0.5 was chosen because: (1) it is compatible with good strength characteristics, (2) it reflects relative economy in mix design, and (3) it does not preclude segregation when the flow value ranges between 95 and 105 percent.

A comparison of the flexural and compressive strength characteristics of 28-day-old mortars, fabricated during the preliminary phases of this program, revealed that distilled water was most desirable as the standard for type of mixing water. Mortars incorporating either brackish or sea water had exhibited larger fluctuations in strength than had the companion distilled-water mortars.

The mortars in the regular series of 597 mixes were of a plastic consistency such as to insure flow values of not less than 95 nor greater than 105 percent when tested for workability in accordance with ASTM Designation C87-52; the water-cement ratio for any mortar was not restricted to 0.6 as specified in that standard method. A predetermined selection of water-cement ratios provided for a variety of aggregate-cement ratios; the latter were adjusted so that workability was within the limits described above. The water-cement ratios used in the Group B Schedule of tests were: 0.3, 0.4, 0.5, 0.7, and 0.9. Though the program as outlined originally did not provide for a water-cement ratio of 0.4, the insertion of this value was indicated by the strength-data gap revealed in the preliminary phases of the Group B Schedule of tests; it was discovered that plotting water-cement ratios against rupture modulus and against compressive strength, for mortars possessing water-cement ratios ranging from 0.3 through 0.9, left much to be desired in the critical area of low ratios. Inclusion of a water-cement ratio of 0.4 was not congruous for all coral-sand mortars, particularly those in short supply.

Every flow table test involved the procedure shown in ASTM Designation C185-53T; the flow table was not motorized. Figures 8 to 12, inclusive, illustrate various stages in a typical test for flow properties of a Guam coral-sand mortar.

Sufficient mortar was produced with each mix to provide not only for individual flow and entrained-air tests, after which the respective mortar quantities were discarded, but also for the fabrication of four prismatic test specimens. The amounts of sand varied with the water-cement ratios; for any one mix the quantity of sand range between 4000 and 7000 gm. The approximate required amounts of water, cement, and sand were based upon experience gained in the preliminary mix series. The quantity of water needed for any particular mix was adjusted in accordance with the percentage absorption of the sand (determined previously in the Group A Schedule) under consideration; the cement content for that particular mix was computed from knowledge of the water-cement ratio value which had been determined previously.

The quantity of coral sand is not dependent upon gradation alone.[2] In some instances, imposition of arbitrary limits upon the percentages of various particle sizes present in the sand would tend to preclude satisfactory coralline materials. Fineness modulus, for example, indicates fairly the measure of particle gradation and size; as such, FM may serve as a guide to the percentage voids present. Nevertheless, FM cannot be employed to predict the great variety of gradations and the variations in aggregate-cement proportions that are common to mortars or concrete; study of Section 10 in Reference 2 corroborates this statement. It is difficult to compare sands only on the basis of mechanical analysis curves because such curves do not reflect necessarily the differences in particle shape and surface texture. Mechanical analysis, furthermore, does not serve as an indicator for bulking of sand nor does it demonstrate the differences in bulking properties provided by variations in particle size or in surface texture; these particle aspects influence bulking to the extent that they are related intimately to moisture absorption.

For such reasons, therefore, FM should not be expected to indicate reliably the flexural or compressive strength values attainable with various coral mortars and coral concretes. Gradation of aggregate has some effect, of course, upon the relationship between water-cement ratio and strength, but of more importance is the fact that gradation influences greatly the workability and economy of the mortar or concrete mixture. In the Group B Schedule the objective was to compare coral fine aggregates on an equal basis (i.e., equal workability as determined by restricting mortar flow values to a narrow band that ranges from 90 to 110 percent). Comparing coral-sand mortars with the

Figure 8. Molding mortar sample preparatory to flow test.

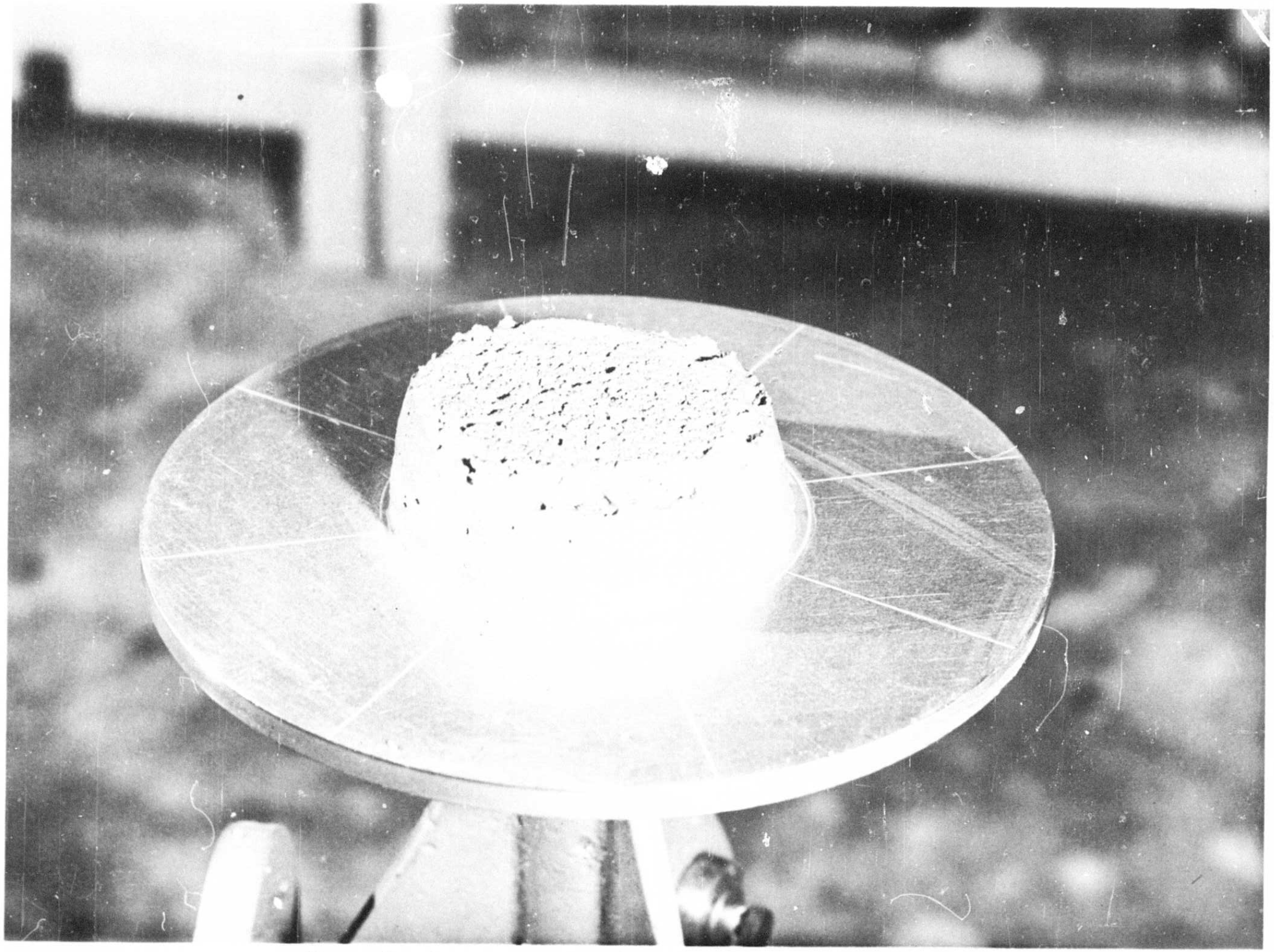


Figure 9. Appearance of relatively rich coral mortar sample immediately prior to flow test.

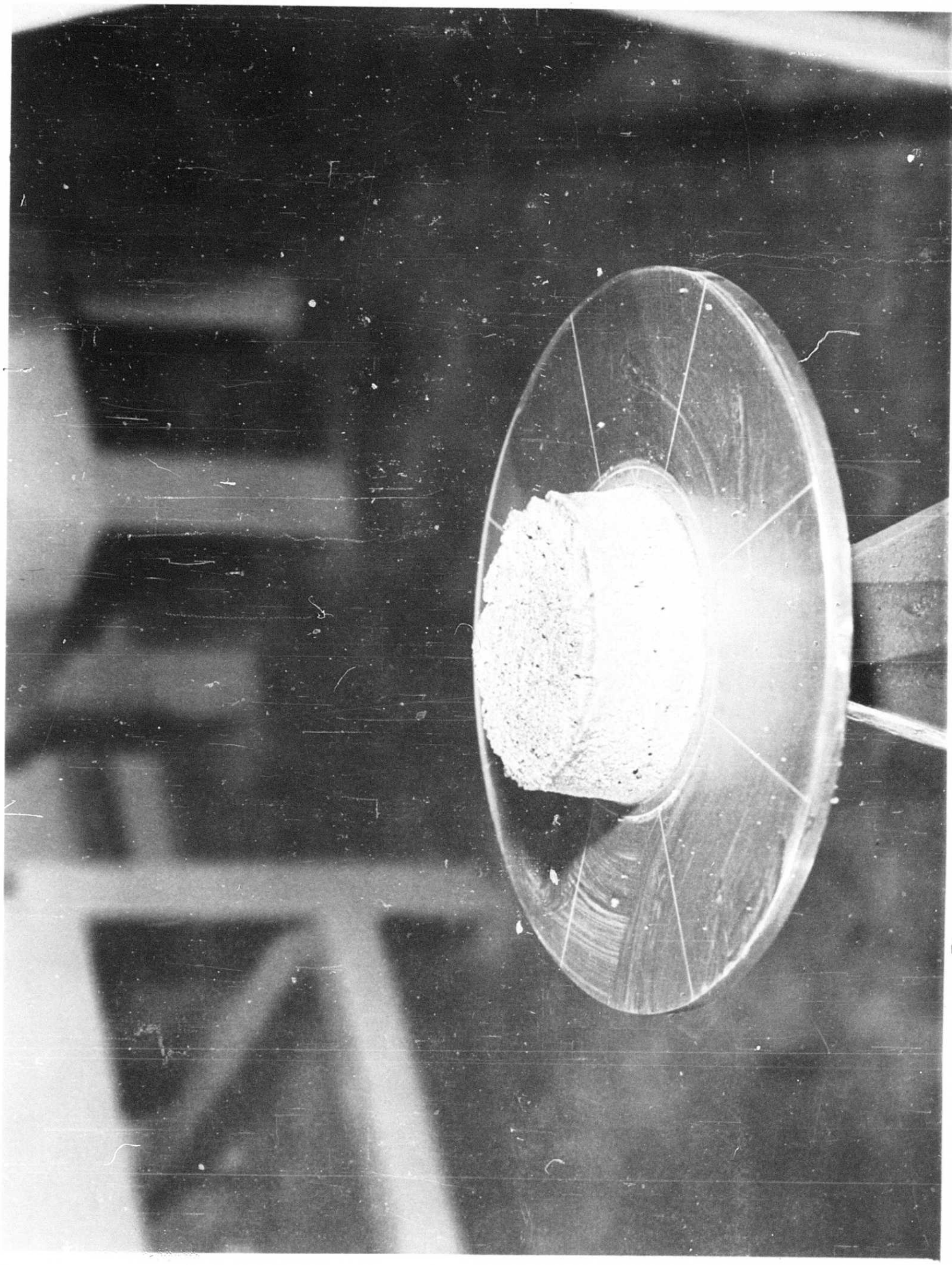


Figure 10. Appearance of relatively lean coral mortar sample immediately prior to flow test.

Figure 11. Flow exhibited by mortar sample shown in Figure 9.

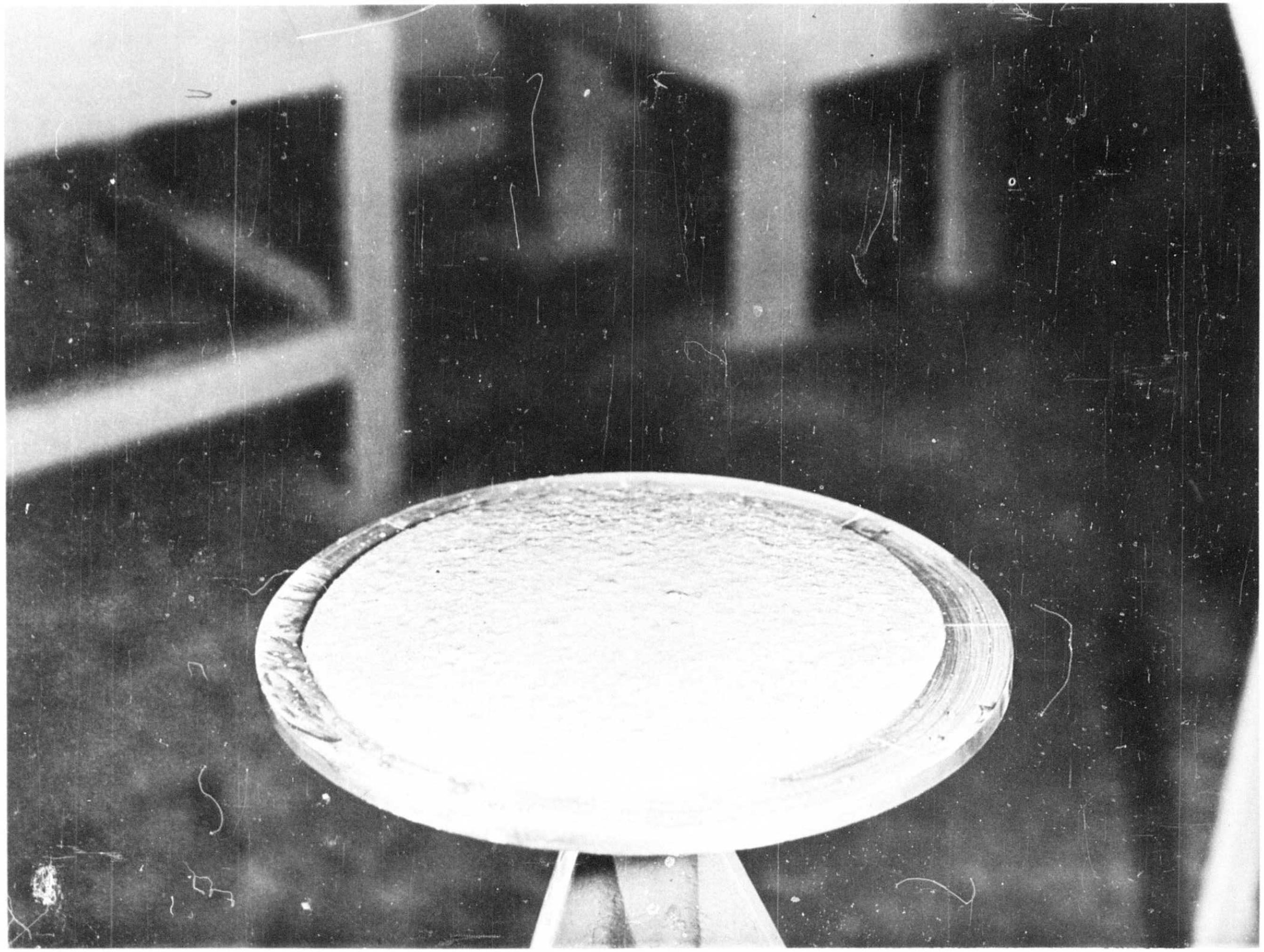


Figure 12. Flow exhibited by mortar sample shown in Figure 10.

reference mortars, which incorporate OO and SS sands, involves various cement content values. As concrete mixtures represent a diversity of mortar richnesses, it follows that a study of those mortars possessing a common richness (i.e., equal cement content per unit of absolute volume of mortar) and a common percentage of flow should be an effective means of determining the comparative mortar characteristics of the coral sands involved.

A number of theories have been advanced in America for the ideal gradation of aggregate for use in mortar or in concrete. In the author's estimation, the most important of these are the methods promulgated by Fuller and Thompson,[7] by Talbot,[8] and by Weymouth[9]; their contributions have been the subject of extensive controversy[10,11]. The relative merits of each method were studied for the purpose of ascertaining which was best suited as a research tool in the coral mortar study. Weymouth's ideal grading showed the greatest promise and was chosen because of its rational approach to the problem of designing dense coral mortar mixes. Weymouth's method is based upon a theory of particle interference which is more compatible with the mechanics of particle rearrangement (incident to aggregate blending) than the other methods and which is more readily applicable to analyses of data pertaining to ideal gradation or natural gradation. An explanation of the various theories comprises Appendix I.

The Weymouth method is not perfect but it most nearly meets the requirements of optimum gradation for mortars or concretes; it tends to approach an economical mix but it does not necessarily give the most dense mix because of the impracticability of allowing for actual particle-shape and actual particle-size distribution within the mass of each size fraction comprising the aggregate under consideration. The other two so-called ideal gradations are considered to be curve-fitting techniques.

The use of an ideal gradation curve in connection with grading aggregates for mortar or concrete might be undesirable for other than laboratory experimentation, due mainly to the resultant harshness (of the mix) caused by the relatively small portion of fines present.

Consideration of all three methods leads to the admission that in actual practice the truly ideal gradation curve may be approached but is never realized. At the construction site a constant value of specific gravity is assumed for the particular sand in question; likewise, within each size fraction the particle distribution is assumed to be uniform. Notwithstanding these assumptions, the effect of particle shape invariably is poorly defined. Therefore all ideal curves must be viewed with caution; at best, they serve as reference levels for the design of dense mixes, be they mortar or concrete.

In view of the foregoing explanations the laboratory gradations employed in the Group B Schedule were reduced to the following two categories:

(1) Natural. This included minor gap gradation usually associated with as-received coral beach sands but excluded any distinct gaps made empirically for experimental purposes.

(2) Ideal. This provided for use of crushed coralline materials recombined to conform to Weymouth's ideal curve but excluded any blends conforming to ASTM Designation C33-54T.

The general plan for the Group C Schedule of tests, had the experimentation been continued, would have been to correlate gradation categories (1) and (2) with the physical characteristics of the various concrete mixes contemplated. Such concrete mixes would have incorporated the majority of the coral-sand mortar types comprising the Group B investigation.

CHAPTER 3 END NOTES

3.1 The only means of controlling ambient heat and moisture were, respectively, by a thermostat-controlled steam space-heater suspended from the ceiling and by manipulating windows or placing wet towels over the louvers of the heater fans. The range of observed air temperature was 70 to 80 F and the range of observed relative humidity was 30 to 60 percent throughout the entire period devoted to batching, mixing, and fabrication of nearly 2400 mortar specimens.

3.2 Interior dimensions 2.00 in. by 2.00 in. by 11.19 in.

3.3 Opaque cloth backing, water- and oil-resistant, low moisture-vapor transmission rate, adhesive coating on one side only; identifiable as G8135-273-9850 series in Navy Stock List of General Stores Catalog. Tape conformed to Federal Specification PPP-T-60, type I, class 1.

3.4 Interior dimensions 2.00 in. by 2.00 in. by 11.00 in. for each compartment.

Chapter 4

TESTING METHODS

9. TEST PRINCIPLES INVOLVED

In the interests of expediting the test program, tensile strength of mortar briquets and compressive strength of standard mortar cubes were features that were considered complementary rather than requisite to the research and consequently these types of specimens were not used. Flexure tests of rectangular mortar prisms, and compressive strength determinations of modified cubes derived therefrom, furnish all essential data pertaining to resistance of mortars in tension, shear, and compression.

Glanville [12], who at the time was concerned primarily with mortar tests as a means of depicting the strength properties of portland cement, showed that the expected compressive strength of concrete is indicated by the compressive strength values of standard mortars (incorporating, on a weight basis, 12.5 percent water and an aggregate-cement ratio of 3) and can be estimated within 10 percent customarily. According to Glanville, "The best guide to the transverse strength of concrete is given by the transverse strength of wet mixes of 1:3 standard sand mortar, although the tensile strength of these mixes is practically as good....Since, however, tensile strength tends to a limiting value at an earlier age than compressive strength, and a small change in transverse strength is then accompanied by a large change in compressive strength, it would seem advisable in estimating the properties of a cement [or the coral sand] to examine both the transverse and compressive strengths."

The transverse strength is expressed most conveniently by the rupture modulus. The flexural test currently is conducted as per ASTM Designation C348-54T and the modulus is computed as per ASTM Designation C78-49; these aspects are described more fully in Section 13. Under transverse loading the extreme-fiber stresses on the tension and compression sides of a rectangular prism of homogeneous material are equal; as mortar is not truly homogeneous and as its tensile strength is but a small fraction of its compressive strength, obviously the flexural strength of mortar depends upon its tensile strength. The rupture relationships developed in Part II are valid, nevertheless, since they are based on rupture modulus values that are very nearly proportional to the true extreme-fiber stresses. The extreme-fiber stress so computed actually is in excess of the true stress and therefore the rupture moduli, indicated for the various specimens under transverse loads, exceed the true tensile-strength values.

With regard to evaluating the tensile strength of the mortar prisms, no formulae are known whereby the rupture moduli may be used directly; nor is any method known whereby the rupture modulus may be multiplied by some constant which is related to the support conditions and to the specimen dimensions. The only sufficiently precise and direct method of ascertaining actual tensile strength appears to be that which entails mortar briquets and which was discussed by the author elsewhere.[13]

Tucker[14] has shown that the rupture modulus is independent of the width of the rectangular prism and that the modulus value tends to decrease as the prism length or depth increases. His study also indicated that variations in prism length (within a range as high as five times the shortest length) do not affect the rupture modulus values for prisms loaded at the third-points, whereas those prisms that are center-loaded suffer a loss in modulus as the length is increased, although modulus values of center-loaded prisms always are greater than those for similar prisms subjected to two-point loading.

The bending moment of a prism under center-point loading is not constant in the middle portion (as with third-point loading) but increases linearly from zero at the supports to a maximum at the center. Short prisms (e.g., where the length is less than five times the depth) loaded at third points tend to fracture through sections not near the loads. Consideration of these features plus the facts developed by Tucker led to the obvious desirability of using 2-in. by 2-in. by 11-in. prismatic specimens subjected to third-point loading. This type of test served as an unquestionable means of investigating the tensile and shear properties of the various coral mortars.

10. AIR CONTENT

Entrained air in mortars, unlike entrapped air which is present in harsh mixtures because of poor consolidation, varies considerably with the gradation and the petrographical nature of the sand and regardless of the fact that the water-cement ratio may be constant. The total void content, comprised of air and water, is the basic factor that governs the strength properties of the mortar. Clusters of air globules are formed about each sand grain in the MINUS 30 PLUS 100 size group; such bubbles do not congregate about the cement particles nor about MINUS 100 sand particles.

The method followed in determination of air content was that indicated in the ASTM standard existent at the time[4.1] except that each layer was spaded ten times. A 400.0-ml calibrated brass container was filled with mortar in three layers, tapped five times when full, and screeded with a straightedge in two passes made 90 degrees apart. The container and contents were weighed[4.2] and the air content calculated. This quick test was made immediately after each flow determination.

11. BULK DENSITY

All prisms of hardened mortar were tested for bulk density[4.3] within 24 ± 2 hours after fabrication. Density determinations also were made at appropriate later ages (i.e., 7, 28, 91, and 364 days) depending upon the particular specimens scheduled for observation and always immediately prior to flexural strength tests. The method employed in obtaining these bulk density (SSD basis) data was similar to that used throughout the Group A Schedule in determining bulk specific gravity of coarse coral aggregate; the philosophy of this method involves use of data concerning the weight of water displaced by total immersion of the specimen. The basic weighing apparatus was a commercial scale equipped with a nonius dial graduated in 1-gm divisions (capacity 5000 gm and sensitivity reciprocal 0.5 gm).

12. VOLUME CHANGE AND WEIGHT CHANGE

The program did not provide for length-change measurements of mortar specimens mainly because certain coral sands were in short supply. Numerical values pertaining to changes in volume and weight, however, were developed for mortars fabricated with natural-graded AMBf, BJBf, GMRf, and SS sands and with the standard-graded OO sand; these mortars incorporated water-cement ratios of 0.3, 0.4, 0.5, 0.7, and 0.9 and involved sea, brackish, or distilled water. These were the only mortars for which complete ranges of water-cement ratio values and types of mixing water were obtained. Regular prismatic specimens served satisfactorily in the observance of the weight and free volume changes exhibited by the various hardened mortars.

A work sheet entitled "Volume Change of Hardened Mortar With Age" was developed to expedite computations. Work Sheet WRL-1, in Appendix III, illustrates typical entries for Mix 234 which incorporated GMRf sand; the computations are explained below. A negative or positive change in volume is designated respectively as shrinkage or swelling; such changes are not designated contraction nor expansion as these latter terms[15] relate to volume changes caused by thermal variations. The prisms observed were subjected to fog storage at temperature 73.4 ± 2 F; the ambient thermal conditions during observations were maintained at 73 ± 5 F. Each of the four prisms of any one mix were weighed in air and in water at age 24 ± 2 hours. Each of these specimens was weighed likewise at its respective age (e.g., 7, 28, 91, or 364 days) immediately before the strength test at the designated age.

The volume change computations were based upon the assumption that the percentage of air entrained in the mortar while plastic remained constant thereafter; stated otherwise, the percentage of entrained air in the hardened mortar specimens was assumed equal, at any age, to the value observed for the plastic mortar mix whence the prisms were derived. The amount of displaced water[4.4], expressed in gm, was assumed equivalent to a like number of cubic centimeters of 73 F water.

The solid-state absolute volume of the prism is equal to the product of [volume of displaced water] and [100 percent minus percent of entrained air], whereas the plastic-state absolute volume of the same specimen is equal to the product of [volume of prism mold] and [100 percent minus percent of entrained air]. For example, consider Mix 234 and the specimen tested for strength at age 7 days. Measurements to the nearest 0.1 gm indicated that the amount of entrained air in this mix was 2.5 percent; other measurements to the nearest gram indicated that

SSD prism weight in 73 F air = B = 1590. gm,
SSD prism weight in 73 F water = C = 871. gm,
Weight of displaced water at 73 F = 719. gm,
and Volume of displaced water at 73 F = 719. cc.

Since the specimen under consideration was cast in a gang mold, the volume of air within the plastic-state prism was, for all practical purposes,

$$(721.\ \text{cc})(2.5\%) = 18.\ \text{cc},$$

which also was the volume of air contained within the hardened prism. The absolute volume of the prism in the solid state was

$$(719.\ \text{cc}) - (18.\ \text{cc}) = 701.\ \text{cc}$$

and the absolute volume of the same specimen while in the plastic state was

$$(721.\ \text{cc})(100\% - 2.5\%) = 703.\ \text{cc}.$$

The change in volume attained at age 24 hours was the difference between [solid-state absolute volume at 24 hours] and [plastic-state absolute volume at 0 hr], or

$$(701.\ \text{cc}) - (703.\ \text{cc}) = -2.\ \text{cc},$$

which was equivalent to a shrinkage of

$$[(-2.\ \text{cc}) \div (703.\ \text{cc})]\ 100 = 0.3 \text{ percent}.$$

The volume changes attained at subsequent ages were computed similarly; the data concerning the companion prisms for Mix 234 showed

0.6 percent swelling at age 7 days,
0.1 percent shrinkage at age 28 days,
0.3 percent shrinkage at age 91 days,
and 0.1 percent shrinkage at age 364 days.

Work Sheet WRL-2 entitled "Weight Change of Hardened Mortar With Age" was developed incident to the requisite computations and is included in Appendix III to illustrate typical entries concerning weight changes observed with GMRf mortars. The procedure merely involved determination of the difference between the bulk density at a specified age and the unit weight of the mix whence the hardened prism had been derived. Measurements in connection with the actual or experimental density of the plastic mortar were obtained as indicated in Form WRL-12, which contains typical entries. Using GMRf mortar Mix 234 as an example, the actual unit weight of the plastic mortar was computed as 137.10 pcf, which value was the basis for the weight changes shown in the example comprising Work Sheet WRL-2.

13. FLEXURAL STRENGTH

The two-point flexure testing apparatus was a modification of that proposed for a new ASTM testing method.[16] Figure 13 depicts the two-point loading device used.

The testing procedure incorporated certain sections of ASTM Designation C78-49 and selected portions of the proposed method.[4,5] To insure an extreme-fiber stress-increase rate of 150 psi per minute required a loading rate of 120 lb per minute for the last half of the ultimate load; the first half of the ultimate load was applied more rapidly in all cases. The slowest loading rate that could be maintained in the 60,000-lb-capacity universal testing machine was 133 lb per minute; this was the only departure from the prerequisite concerning flexural loads that were to be compatible with the extreme-fiber stress-increase rate specified.

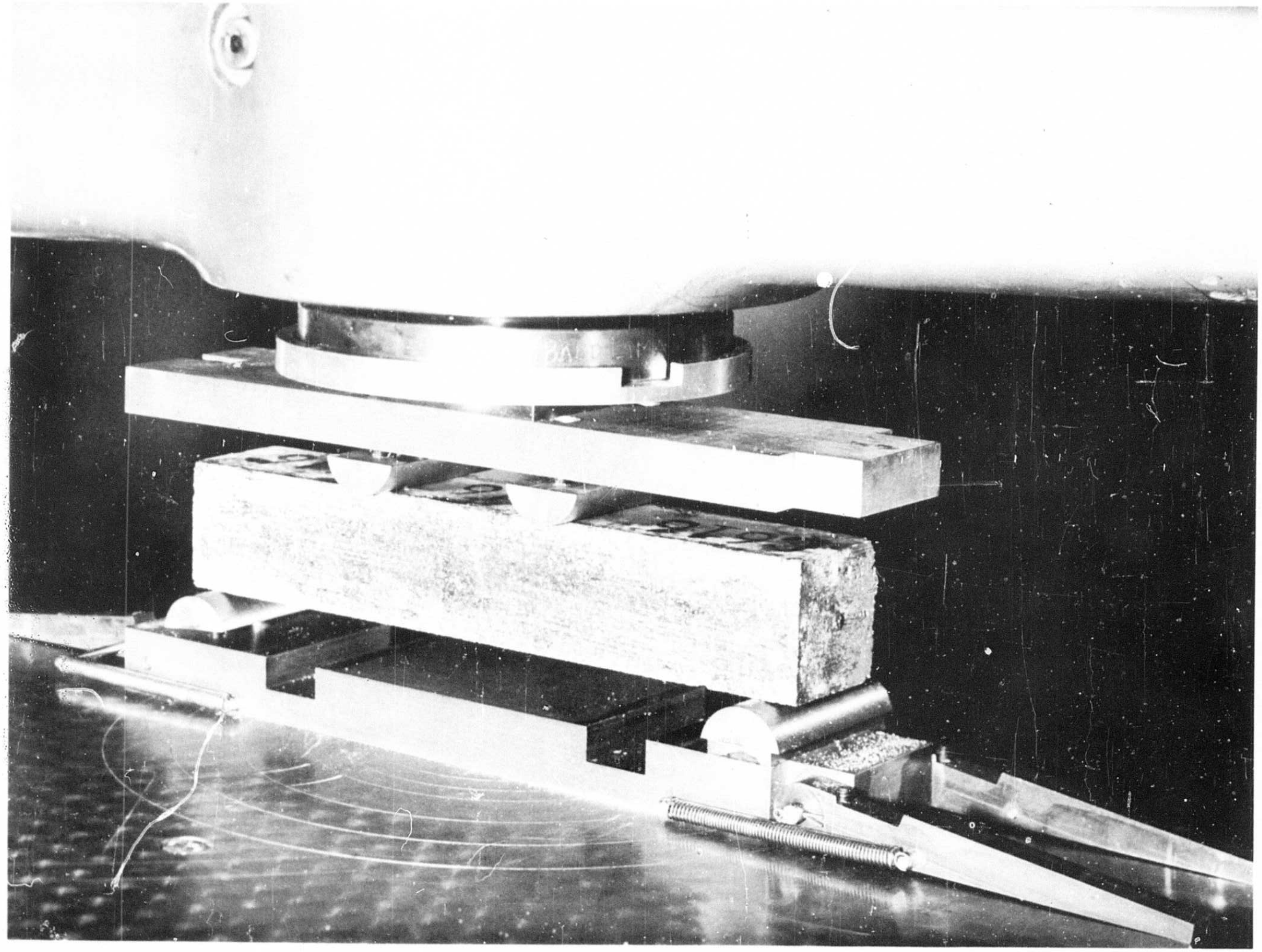


Figure 13. Two-point flexural loading device in operation.

The flexural tests were based on certain principles, discussed in Section 9, which involved the following presumptions: (1) prisms are dimensionally constant by virtue of being cast in relatively rigid steel molds, (2) testing apparatus at all times is aligned properly under the crosshead of the testing machine, (3) mortar is homogeneous and the mortar prism obeys the elastic theory during flexure, and (4) prisms are tested as simple beams. Predicated on the above, transverse strength is indicated by the magnitude of the rupture modulus which commonly is computed as:

$$S_t = \frac{Mc}{I};$$

where S_t = apparent extreme-fiber tensile stress

$M = \frac{P\ell}{6}$ = maximum bending moment, which is constant throughout middle third of specimen where shear is zero,

c = distance from neutral axis to extreme fiber, or one-half the depth (d) of rectangular cross section of specimen,

P = total load,

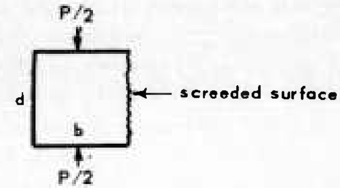
ℓ = total length of span between supports,

$I = \frac{bd^3}{12}$ = moment of inertia of rectangular cross section,

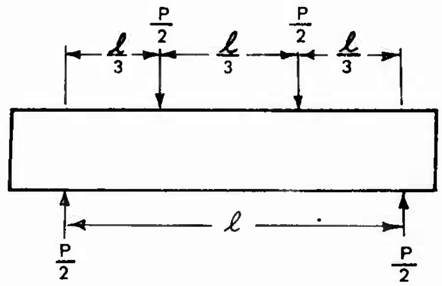
b = width of rectangular cross section of specimen,

and d = depth of rectangular cross section of specimen.

As the depth is cubic in the expression for moment of inertia, it is important to orient the prism cross section so that the screeded face (i.e., the original top surface) becomes the side when the specimen is under third-point loading P. This is shown diagrammatically as:



The flexural test used throughout the Group B Schedule entailed loading the prism, at the third-points of a 10-in. span, in the self-adjusting device illustrated in Figure 13. The loading arrangement is represented thus:



Using the above equation, it can be shown that the rupture modulus is equal to 1.25P psi.

14. COMPRESSIVE STRENGTH

The modified cubes derived from the prisms were tested in compression in the machine used for flexural tests. The alignment jig and bearing blocks, shown in Figure 14, were designed and constructed specifically for this investigation with the view of minimizing test data dispersion normally caused by the personal factor incident to this type of test.

The procedure followed in load application was based partly on ASTM Designations C109-54T and partly on C349-54T. The important aspect was the following proviso: if the ultimate load was 3000 lb or greater, the first half of

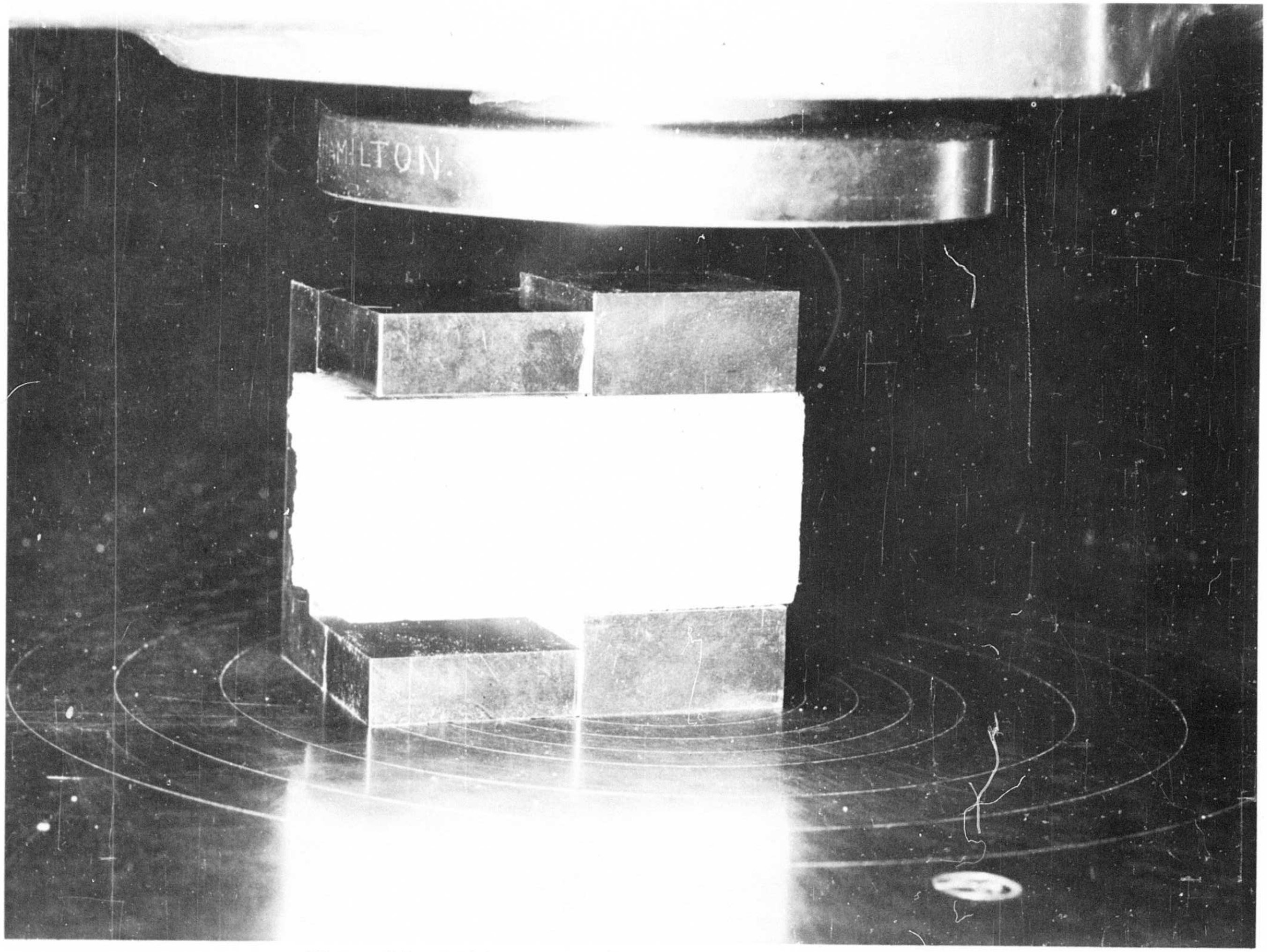


Figure 14. MCS specimen between bearing blocks at right and positioned by alignment jig at left.

that ultimate load could be applied at any convenient rate, but the last half of the load was to be applied so that the ultimate load would be attained between 20 and 80 seconds after the beginning of the last-half loading phase. The average loading rates for the last half of P were as follows:

Specimen Age, days	Last Half of P, lb per minute
7	4,100
28	16,900
90 or more	35,600

These rates were the median values between the 20- and 80-second rates. For cases where the expected load at fracture was less than 3000 lb, a constant rate of 2500 lb per minute was used from beginning to end of test.

15. DYNAMIC ELASTIC MODULUS

The fundamental transverse frequencies of the mortar prisms were determined immediately prior to test for flexural strength. The procedure essentially was as outlined in ASTM Designation C215-52T. The sonic apparatus available throughout the Group B Schedule did not provide a satisfactory means of ascertaining the torsional frequencies of the prismatic specimens.

The constant in the equation for Young's modulus of elasticity,

$$E = CWn^2,$$

was evaluated for specimens cast in gang molds as:

$$E' = [(0.00245)(11.00)^3(1.22) \div (2.00)(2.00)^3] \; Wfn^2,$$

whence $$E = (5.483 \times 10^{-4})Wn^2;$$

and for specimens cast in single molds as

$$E' = [(0.00245)(11.19)^3(1.21) \div (2.00)(2.00)^3] \; Wfn^2,$$

whence $$E = (5.729 \times 10^{-4})Wn^2;$$

where E' = Dynamic Young's elastic modulus, gm per sq in.,

E = Dynamic Young's elastic modulus, lb per sq in.,

$C = (0.00245\ L^3T) \div (bt^3)$, second^2 per sq in.,

W = prism weight, gm,

f = factor for converting gm to lb = 2.205×10^{-3},

n = fundamental transverse frequency, cycles per second,

L = prism length, in.,

T = factor related to $(K \div L)$ in Table I of ASTM Designation C215-52T,

b = prism width, in.,

t = prism height, in. (thickness in transverse direction),

and K = radius of gyration for prism = $(t) \div (3.464) = 0.5773$ in.

The values of T were obtained from the tabulation given in ASTM Designation C215-52T; the validity of these values rested on the premise that Poisson's ratio was 0.167. Each observed value of n and each computed value of E was correct to three significant figures (e.g., 233×10^2 cycles per second and 4.76×10^6 psi, respectively).

CHAPTER 4 END NOTES

4.1 The Group B Schedule began before ASTM Designation C185-55T had been published; C185-53T did not specify a fixed number of spadings and therefore the quantity chosen was arbitrary.

4.2 To the nearest 0.1 gm, using a torsion balance (capacity 4500 gm and sensitivity reciprocal 0.5 gm) equipped with a sliding-weight beam graduated in 0.2-gm divisions.

4.3 The following arbitrary distinction is made concerning mortars and concretes: "unit weight" relates to the plastic state and "bulk density" relates to the solid state.

4.4 This quantity appears as (B-C) in Work Sheet WRL-1 in Appendix III.

4.5 Later known as ASTM Designation C348-54T which was published in in 1955 but not distributed until after the Group B Schedule of tests was underway.

Chapter 5

TEST DATA TREATMENT

16. DATA COLLECTION, ADJUSTMENT, AND CORRELATION

The entire Group B Schedule, including the preliminary mix series, involved 621 batches of mortar; the regular series comprised 597 mixes which resulted in 2388 mortar prisms tested at 7-, 28-, 91-, or 364-day ages. Details regarding the quantity of mixes are shown in Table V. All test data concerning these hardened mortars were assembled, analyzed, evaluated, and correlated. Figure 15 is a graphical illustration of the sequence of data treatment. The data adjustment methods, described in this section, were applied to dynamic elastic modulus, rupture modulus, and compressive strength values of the various hardened mortars; data concerning other features (i.e., volume change, weight change, and bulk density) were averaged but were not adjusted.

Mix design information and most of the plastic-mortar test data were recorded on Forms WRL-12 and all data acquired in the testing of the hardened specimens were recorded on Forms WRL-13. Typical data forms appear in Appendix III. To expedite tabulation of data, three additional work sheets were developed; they are identified as "Plastic-Mortar Air Content Summary" (Sheet WRL-3), "Coral Mortar Summary" (Sheet WRL-4), and "Computations of CMC, Yield, and A/C" (Sheet WRL-5). These appear in Appendix III and illustrate typical entries concerning Mix 234.

The use of the procedure (described in Appendix II) for measuring air content values of the various plastic mortars made possible the development of cement factor data (in terms of grams of cement per milliliter of plastic mortar, which values were converted to equivalent pounds of cement per cubic foot of plastic mortar) and mortar yield data (in terms of cubic feet of mortar produced per 94-lb sack of cement). Examples of such cement factor data are shown in Work Sheet WRL-5.

With regard to the mix design data recorded on Forms WRL-12, "net W/C, by wt" was considered the nominal water-cement ratio. Mixing water was measured volumetrically; for sea or brackish water the net water-cement ratio was recorded in ml per gm rather than gm per gm. The water-cement ratio in gm per gm was not obtained by correcting the volumetric water contents for the appropriate water densities (e.g., 1.023 gm per ml for sea water and 1.003 gm per ml for brackish water). Theoretically, the quantity of water alone, rather than the combined weight of water plus soluble salts, was the governing factor in ascertaining the water-cement ratio of each mortar mix tested.

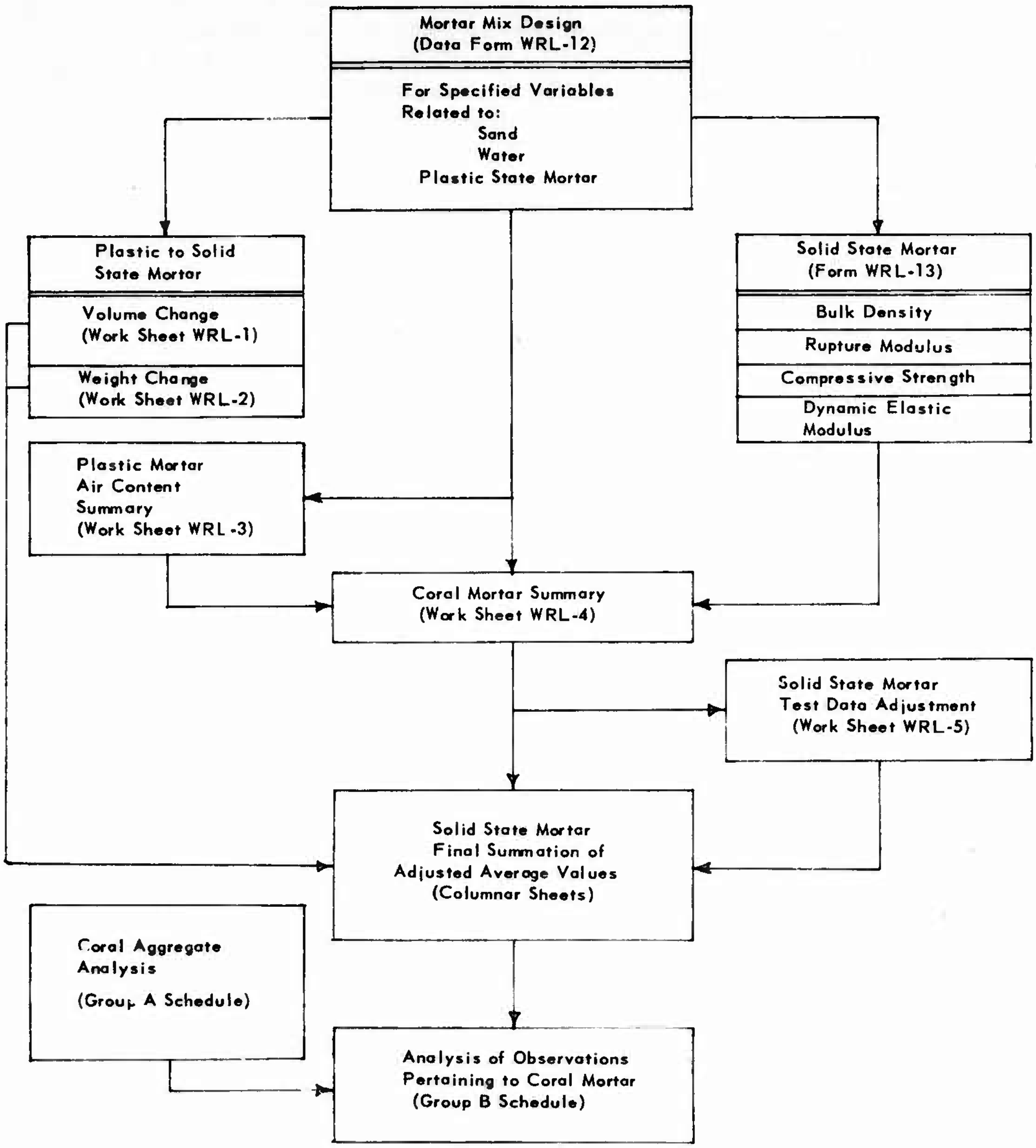


Figure 15. Coral mortar test data sequence chart.

Plastic-mortar air content data were recorded and computed on Work Sheet WRL-3. The weights of constituents in any particular mix were used in computing the theoretical bulk density of the plastic mortar; the experimental or measured density, obtained with the 400.0-ml container, was checked in each instance against the computed theoretical density.

Completed mortar summaries, common to the mixes fabricated with each of the 15 designated sands, were combined in one assemblage. Mortar data that involved ideal-graded sands (ENCRcf, ENPf, ENRf, GMRf, and SS) were segregated from mortar data pertaining to the eleven natural-graded sands (AMBf, BJBf, CLQf, FDQf, GMRf, HMPf, KWCRc37, NNQf, OO, PTQf, and SS).

The mortar test data were segregated relative to certain controlled physical variables (i.e., sand, type of water, and water-cement ratio) for the purpose of analyzing average data values. The mean value of each type of parameter or observed physical characteristic, with regard to ages at 7, 28, 91, or 364 days, was computed. Work sheets for these collections were prepared by transcribing the mean values from the mortar summaries onto columnar sheets as "raw data" which were segregated[5.1] in regard to appropriate variables and physical characteristics. The raw data totals corresponding to each controlled variable were determined as the data were accumulated for the progressive test ages and the raw average value was obtained and recorded for each parameter. Each work sheet pertained to a designated sand of specified gradation (i.e., natural or ideal) and to a specified type of water (i.e., sea, fresh, or brackish).

Any extreme variations in the raw average values of the observed parameters for each hardened mortar[5.2] were accounted for by eliminating arbitrarily all measurements that were beyond ±10 percent of the mean value for that particular parameter. Elimination of such variations required the calculation of new or corrected mean values or "adjusted averages" which, in turn, were checked for possible variation greater than ±10 percent of the new or corrected mean. The discarding of extraneous or incompatible data was repeated when necessary; such instances would seldom occur. This procedure was intended to measure the reliability of the data and not to serve as an analysis of the parameters observed in connection with each plastic mix and its resultant hardened specimens. The adjusted averages of the parameters were recorded immediately below the raw average values on the final columnar sheets. Values of entrained air content of the various mixes in the plastic state were adjusted averages; flow values were averaged but were not adjusted.

For the purpose of this report, a final summation of treated data is given in Tables VII to X inclusive. These tables, which also furnish pertinent information concerning the various mortars and the designated sands involved therewith, summarize the adjusted average data in each of the categories tested. The adjusted average values were plotted as the last stage (final-plot series) of the graphical versions of controlled physical variables versus observed parameters, as appropriate (e.g., water-cement ratio versus rupture modulus); refer to Section 1 for variables involved. The first-stage graphical work (initial-plot series) was performed with regard to individually designated sands; the last-stage was done on the basis of selective groupings of those sands. The adjusted averages were plotted in the first stage merely as a means of quickly checking the relationships involving the following parameters and controlled variables: elastic modulus, rupture modulus, type of water, and age at test.

A desirable analysis of the effects of the controlled variables upon the physical characteristics of the mortars would dictate that the quantity of tests should be sufficiently numerous to assure effectual statistical studies of the resultant test data. Computation of standard deviation or coefficient of variation for the several physical parameters would have entailed very large quantities of data. Pure statistical analysis was unwarranted, if not incompatible, for ascertaining the reliability of the test data acquired; this view was valid in the light of the comparatively small number of measurements imposed by the limited quantities of available coralline materials.

The relatively arbitrary fashion in which the test data were treated was necessitated by a vital need of "finding an answer" within a reasonable interval. Use of the method, however rough, eliminated any data that appeared faulty, served in grouping the data as to variables, and provided a means of detecting data trends wherever large differences appeared. The method assumed that no data were valid unless they were within ± 10 percent of the average used; this, of course, involved recognition of compensatory fluctuations because the 10-percent limitation was empirical and in a few cases direct application of the rule would have meant discarding reasonable test data. The procedure, nevertheless, fitted remarkably well more than 90 percent of the data analyzed.

17. LIMITATIONS OF THE ANALYSIS

The graphical presentations in this publication include the final-plot series and a few graphs of the initial-plot series. The preliminary mix series pertained exclusively to the coral sands that were in plentiful supply; the mix-design data for this series and the resulting initial-plot graphs served as a

Table VII. Time Study of Ope

Aggregate Identification	Nominal W/C, by wt	avg CMC, pcf	avg A/C, by wt	avg YIELD, cfsk*	avg FLOW, %	avg EAC, %	avg UWP, pcf
AMBf (natural-graded)	0.3	52.42	0.50	1.79	97	3.0	134.06
bulk sp gr = 2.60 (SSD)	0.4	34.91	1.16	2.69	98	5.9	129.07
absorp = 3.72% (OD)	0.5	27.04	1.62	3.48	98	9.0	123.39
FM = 2.44	0.7	19.46	2.30	4.83	100	10.0	117.86
	0.9	15.49	3.05	6.07	98	10.0	116.26
BJBf (natural-graded)	0.3	46.17	0.75	2.04	97	3.7	134.20
bulk sp gr = 2.52 (SSD)	0.4	29.57	1.53	3.18	98	8.8	125.81
absorp = 5.61% (OD)	0.5	24.27	1.99	3.87	100	8.5	124.54
FM = 2.72	0.7	18.56	2.64	5.43	98	9.0	120.27
	0.9	14.87	3.29	6.35	100	11.2	116.57
BJBf (natural-graded)	0.3	35.56	0.68	1.96	97	3.6	134.76
ditto except vibrated	0.4	30.85	1.51	3.05	98	6.6	129.13
2 minutes at 0.009-in.	0.5	24.30	1.98	3.87	101	8.4	125.00
amplitude	0.7	18.23	2.67	5.16	98	9.0	120.81
	0.9	14.74	3.27	6.38	98	9.4	118.35
CLQf (field roll-crushed)	0.4	39.02	1.01	2.41	103	1.2	134.70
bulk sp gr = 2.66 (SSD)	0.5	28.26	1.84	3.32	103	2.4	134.21
absorp = 1.00% (OD)	0.7	18.46	3.38	5.10	102	3.9	131.93
FM = 3.20							
ENPcf (natural-graded)	0.5	21.11	2.54	4.45	97	8.7	126.48
bulk sp gr = 2.40 (SSD)							
absorp = 5.10% (OD							
FM = 3.89 for MINUS 4							
FDQf (field roll-crushed)	0.4	33.14	1.55	2.84	103	1.0	138.07
bulk sp gr = 2.59 (SSD)	0.5	24.59	2.47	3.83	102	1.7	137.92
absorp = 2.64% (OD)	0.7	16.99	3.80	5.53	103	3.6	133.00
FM = 3.52							
GMRf (natural-graded)	0.3	48.35	0.74	1.94	99	3.1	137.03
bulk sp gr = 2.64 (SSD)	0.4	29.00	1.81	3.24	99	8.7	129.14
absorp = 1.97% (OD)	0.5	21.86	2.58	4.30	98	11.1	125.42
FM = 2.57	0.7	15.78	3.56	5.96	98	13.4	119.20
	0.9	12.35	4.53	7.61	99	14.5	116.12

Table VII. Time Study of Operations With Single and Gang Molds

avg A/C, by wt	avg YIELD, cfsk*	avg FLOW, %	avg EAC, %	avg UWP, pcf	**Adjusted Average DYE, psi x 10^6				*Adjusted Average FLS, psi				*Adju
					7d	28d	91d	364d	7d	28d	91d	364d	7d
0.50	1.79	97	3.0	134.06	3.50	3.97	4.08	4.36	1031	1127	1166	936	6633
1.16	2.69	98	5.9	129.07	3.48	3.46	3.62	3.87	805	1032	1030	961	4680
1.62	3.48	98	9.0	123.39	2.72	3.06	3.23	3.36	546	841	920	940	2954
2.30	4.83	100	10.0	117.86	2.16	2.45	2.63	2.79	343	513	649	681	1606
3.05	6.07	98	10.0	116.26	1.58	1.94	2.24	2.19	210	282	444	513	871
0.75	2.04	97	3.7	134.20	4.00	4.05	4.13	4.21	947	1173	1031	933	7162
1.53	3.18	98	8.8	125.81	3.35	3.86	3.52	3.63	610	831	961	902	3676
1.99	3.87	100	8.5	124.54	2.74	3.03	3.61	3.21	509	640	847	858	2829
2.64	5.43	98	9.0	120.27	2.28	2.61	2.26	2.77	328	497	590	664	1550
3.29	6.35	100	11.2	116.57	1.59	1.91	2.08	2.22	186	299	385	480	826
0.68	1.96	97	3.6	134.76	3.72	3.83	4.31	4.23	957	1111	1090	923	7189
1.51	3.05	98	6.6	129.13	3.05	3.38	3.66	3.75	684	855	972	914	4599
1.98	3.87	101	8.4	125.00	2.97	3.39	3.21	3.34	483	718	824	812	2521
2.67	5.16	98	9.0	120.81	2.40	2.57	2.75	2.49	227	388	475	577	1159
3.27	6.38	98	9.4	118.35	1.51	1.97	1.90	1.89	146	263	294	406	638
1.01	2.41	103	1.2	134.70	3.04	3.66	4.02	---	735	891	1072	---	4073
1.84	3.32	103	2.4	134.21	2.91	3.52	3.74	---	585	875	1050	---	2970
3.38	5.10	102	3.9	131.93	2.68	---	3.25	---	470	---	834	---	2310
2.54	4.45	97	8.7	126.48	---	3.20	3.14	---	---	718	700	---	---
1.55	2.84	103	1.0	138.07	3.61	3.96	4.35	---	785	1007	1036	---	4113
2.47	3.83	102	1.7	137.92	3.40	3.90	4.22	---	669	917	1030	---	3360
3.80	5.53	103	3.6	133.00	2.55	3.04	3.71	---	394	606	827	---	1925
0.74	1.94	99	3.1	137.03	4.48	4.22	4.46	4.42	997	1153	1128	1002	7062
1.81	3.24	99	8.7	129.14	3.75	3.62	3.81	4.52	616	854	916	813	3576
2.58	4.30	98	11.1	125.42	3.10	3.34	3.95	4.40	427	617	676	832	2260
3.56	5.96	98	13.4	119.20	2.28	2.82	3.13	3.09	246	406	515	587	1140
4.53	7.61	99	14.5	116.12	1.68	2.11	2.54	2.36	146	248	318	381	585

2

s With Single and Gang Molds

ljusted Average DYE, psi x 10^6			*Adjusted Average FLS, psi				*Adjusted Average MCS, psi			
28d	91d	364d	7d	28d	91d	364d	7d	28d	91d	364d
3.97	4.08	4.36	1031	1127	1166	936	6633	8288	9528	10805
3.46	3.62	3.87	805	1032	1030	961	4680	5956	6883	7686
3.06	3.23	3.36	546	841	920	940	2954	4098	5206	5476
2.45	2.63	2.79	343	513	649	681	1606	2363	3021	3421
1.94	2.24	2.19	210	282	444	513	871	1274	1782	2182
4.05	4.13	4.21	947	1173	1031	933	7162	9029	10259	10602
3.86	3.52	3.63	610	831	961	902	3676	4600	6271	6812
3.03	3.61	3.21	509	640	847	858	2829	4117	5015	5649
2.61	2.26	2.77	328	497	590	664	1550	2380	3209	3419
1.91	2.08	2.22	186	299	385	480	826	1302	1726	2186
3.83	4.31	4.23	957	1111	1090	923	7189	8826	9686	11209
3.38	3.66	3.75	684	855	972	914	4599	6077	7081	7820
3.39	3.21	3.34	483	718	824	812	2521	4003	5092	5344
2.57	2.75	2.49	227	388	475	577	1159	1791	2463	2882
1.97	1.90	1.89	146	263	294	406	638	1041	1380	1458
3.66	4.02	---	735	891	1072	---	4073	6124	6986	---
3.52	3.74	---	585	875	1050	---	2970	5111	---	---
---	3.25	---	470	---	834	---	2310	---	4292	---
3.20	3.14	---	---	718	700	---	---	3452	3931	---
3.96	4.35	---	785	1007	1036	---	4113	5868	7228	---
3.90	4.22	---	669	917	1030	---	3360	4563	5896	---
3.04	3.71	---	394	606	827	---	1925	2908	4048	---
4.22	4.46	4.42	997	1153	1128	1002	7062	8847	9206	10593
3.62	3.81	4.52	616	854	916	813	3576	4913	5732	6631
3.34	3.95	4.40	427	617	676	832	2260	3406	4412	4970
2.82	3.13	3.09	246	406	515	587	1140	1716	2500	2896
2.11	2.54	2.36	146	248	318	381	585	1025	1391	1677

3

Table VII. Time Study of Operati

Aggregate Identification	Nominal W/C, by wt	avg CMC, pcf	avg A/C, by wt	avg YIELD, cfsk*	avg FLOW, %	avg EAC, %	avg UWP, pcf
HMPf (natural-graded)	0.4	35.55	1.15	2.64	103	4.1	130.30
bulk sp gr = 2.60 (SSD)	0.5	27.18	1.74	3.46	102	6.3	127.67
absorp = 3.72% (OD)	0.7	18.68	2.76	5.03	101	8.4	122.58
FM = 1.54							
KWCRc37 (field jaw-crushed)	0.4	37.04	0.98	2.54	98	4.3	129.41
bulk sp gr = 2.23 (SSD)	0.5	27.43	1.60	3.43	99	6.3	126.23
absorp = 5.77% (OD)	0.7	18.85	2.58	4.99	95	7.5	122.22
FM = 1.52 for MINUS 4							
NNQf (field roll-crushed)	0.4	28.15	1.55	3.34	102	2.4	129.23
bulk sp gr = 2.35 (SSD)	0.5	21.62	2.33	4.35	102	3.1	128.36
absorp = 9.45% (OD)							
FM = 2.17							
OO (graded per ASTM C109)	0.3	46.52	0.85	2.02	98	1.8	138.02
bulk sp gr = 2.64 (SSD)	0.4	32.04	1.83	2.94	101	3.7	136.90
absorp = 0.07% (OD)	0.5	23.55	2.56	3.99	101	4.4	133.36
FM = 1.77	0.7	17.45	3.54	5.38	100	5.0	130.30
	0.9	14.11	4.38	6.67	99	4.4	128.38
PTQf (field roll-crushed)	0.5	22.88	2.94	4.11	101	4.6	134.79
bulk sp gr = 2.56 (SSD)	0.7	15.04	4.52	6.26	99	5.4	132.40
absorp = 2.79% (OD)							
FM = 3.87							
SS (graded per Calif Hwy	0.3	51.02	0.65	1.84	98	1.1	138.98
Div 1954 std specs)	0.4	32.76	1.66	2.87	100	1.3	139.28
bulk sp gr = 2.63 (SSD)	0.5	25.74	2.30	3.65	102	1.8	137.37
absorp = 1.37% (OD)	0.7	18.26	3.51	5.15	100	2.2	134.61
FM = 2.88	0.9	13.32	4.44	7.05	102	2.3	133.21
SS (graded per Calif Hwy	0.4	32.37	1.67	2.91	101	2.5	137.47
Div 1954 std specs)	0.5	24.52	2.44	3.83	98	3.5	136.01
ditto except vibrated	0.7	17.88	3.58	5.26	96	3.6	133.36
2 min at 0.009-in. amplitude	0.9	13.68	4.65	6.87	100	5.5	129.05

Note: (1) All prisms cured and stored in 73.4±2 F air at 100-percent RH.
* Cu ft of mortar per sack of cement.
**Prism compaction: hand-tamped unless noted otherwise.

Table VII. Time Study of Operations With Single and Gang Molds (Cont'd)

vg /C, wt	avg YIELD, cfsk*	avg FLOW, %	avg EAC, %	avg UWP, pcf	**Adjusted Average DYE, psi x 10^6				*Adjusted Average FLS, psi				*Adjusted Av	
					7d	28d	91d	364d	7d	28d	91d	364d	7d	28d
.15	2.64	103	4.1	130.30	3.30	3.68	4.06	---	777	1024	1108	---	4613	623
.74	3.46	102	6.3	127.67	2.93	3.30	3.53	---	610	869	925	---	3141	442
.76	5.03	101	8.4	122.58	2.14	2.67	2.78	---	368	556	688	---	1622	249
.98	2.54	98	4.3	129.41	2.87	3.21	3.62	---	761	1023	1067	---	4583	625
.60	3.43	99	6.3	126.23	2.54	2.95	3.03	---	587	896	934	---	3405	462
.58	4.99	95	7.5	122.22	2.10	2.85	2.60	---	407	588	671	---	1794	282
.55	3.34	102	2.4	129.23	3.20	3.03	3.21	3.35	583	799	946	975	3363	521
.33	4.35	102	3.1	128.36	2.38	2.81	2.98	3.17	519	767	858	923	2634	373
.85	2.02	98	1.8	138.02	4.67	5.02	4.56	5.06	1008	1221	1279	1189	7178	931
.83	2.94	101	3.7	136.90	4.28	4.78	4.68	5.35	798	1054	1037	1004	5021	679
.56	3.99	101	4.4	133.36	3.83	4.36	4.12	4.45	549	734	892	825	2998	482
.54	5.38	100	5.0	130.30	3.18	3.75	3.76	4.24	317	519	669	570	1612	294
.38	6.67	99	4.4	128.38	2.45	2.83	3.47	3.30	206	346	463	427	973	179
2.94	4.11	101	4.6	134.79	3.21	3.67	---	---	576	802	---	---	3001	405
.52	6.26	99	5.4	132.40	2.78	3.17	---	---	403	600	---	---	1758	256
0.65	1.84	98	1.1	138.98	3.83	4.23	4.52	4.85	919	1088	1050	898	6441	803
1.66	2.87	100	1.3	139.28	3.68	4.15	4.56	4.71	742	931	1053	1028	3977	601
2.30	3.65	102	1.8	137.37	3.25	3.93	4.20	3.99	587	812	987	980	2970	521
3.51	5.15	100	2.2	134.61	2.54	3.34	3.68	3.82	345	592	769	760	1573	317
4.44	7.05	102	2.3	133.21	1.79	2.72	3.11	3.31	175	393	598	569	791	189
1.67	2.91	101	2.5	137.47	3.63	2.54	4.69	4.65	671	924	1019	924	4114	609
2.44	3.83	98	3.5	136.01	3.15	2.30	4.45	4.11	456	645	944	841	2972	474
3.58	5.26	96	3.6	133.36	2.58	3.21	3.47	3.97	253	477	758	688	1383	282
4.65	6.87	100	5.5	129.05	1.74	2.61	2.88	2.93	128	243	350	366	780	170

ir at 100-percent RH.

se.

2

Single and Gang Molds (Cont'd)

usted Average DYE, psi x 10^6			*Adjusted Average FLS, psi				*Adjusted Average MCS, psi			
28d	91d	364d	7d	28d	91d	364d	7d	28d	91d	364d
3.68	4.06	---	777	1024	1108	---	4613	6234	7253	---
3.30	3.53	---	610	869	925	---	3141	4424	5528	---
2.67	2.78	---	368	556	688	---	1622	2494	2973	---
3.21	3.62	---	761	1023	1067	---	4583	6252	7838	---
2.95	3.03	---	587	896	934	---	3405	4620	5920	---
2.85	2.60	---	407	588	671	---	1794	2826	3656	---
3.03	3.21	3.35	583	799	946	975	3363	5219	5870	6538
2.81	2.98	3.17	519	767	858	923	2634	3732	4604	5182
5.02	4.56	5.06	1008	1221	1279	1189	7178	9313	9835	11598
4.78	4.68	5.35	798	1054	1037	1004	5021	6796	7786	8902
4.36	4.12	4.45	549	734	892	825	2998	4824	6196	6374
3.75	3.76	4.24	317	519	669	570	1612	2941	3801	3933
2.83	3.47	3.30	206	346	463	427	973	1798	2456	2607
3.67	---	---	576	802	---	---	3001	4059	---	---
3.17	---	---	403	600	---	---	1758	2569	---	---
4.23	4.52	4.85	919	1088	1050	898	6441	8038	9101	10988
4.15	4.56	4.71	742	931	1053	1028	3977	6017	7301	8946
3.93	4.20	3.99	587	812	987	980	2970	5214	6170	7218
3.34	3.68	3.82	345	592	769	760	1573	3174	4269	4698
2.72	3.11	3.31	175	393	598	569	791	1895	2618	3052
2.54	4.69	4.65	671	924	1019	924	4114	6090	7168	8942
2.30	4.45	4.11	456	645	944	841	2972	4741	6126	7019
3.21	3.47	3.97	253	477	758	688	1383	2826	3790	4127
2.61	2.88	2.93	128	243	350	366	780	1700	2386	2786

3

Table VIII. Final Summation of Adjusted Average Str

Aggregate Identification	Nominal W/C, by wt	avg CMC, pcf	avg A/C, by wt	avg YIELD, cfsk	avg FLOW, %	avg EAC, %
ENCRcf (ideal-graded) bulk sp gr = 2.58 (SSD) absorp = 2.22% (OD) FM = 3.03 for MINUS 4	0.5	26.18	2.26	3.59	104	1.6
ENPcf (ideal-graded) bulk sp gr = 2.40 (SSD) absorp = 5.10% (OD) FM = 3.03 for MINUS 4	0.5	27.91	1.98	3.37	99	2.0
ENPcf (ideal-graded) bulk sp gr = 2.40 (SSD) absorp = 5.10% (OD) FM = 1.45 for MINUS 16	0.5	30.41	1.49	3.09	98	2.1
ENQcf (ideal-graded) bulk sp gr = 2.46 (SSD) absorp = 3.83% (OD) FM = 3.03 for MINUS 4	0.5	24.80	2.38	3.79	101	2.8
ENQcf (ideal-graded) bulk sp gr = 2.46 (SSD) absorp = 3.83% (OD) FM = 1.45 for MINUS 16	0.5	27.35	1.76	3.44	102	4.1
ENRcf (ideal-graded) bulk sp gr = 2.55 (SSD) absorp = 2.32% (OD) FM = 3.03 for MINUS 4	0.5	25.55	2.27	3.68	104	3.0
ENRcf (ideal-graded) bulk sp gr = 2.55 (SSD) absorp = 2.32% (OD) FM = 1.45 for MINUS 16	0.5	28.80	1.61	3.26	103	4.9
GMRf (ideal-graded) bulk sp gr = 2.64 (SSD) absorp = 1.97% (OD) FM = 3.03 for MINUS 4	0.4 0.5 0.7	35.64 24.73 16.28	1.11 2.04 3.29	2.67 3.82 5.78	101 100 102	5.1 8.7 12.9
SS (ideal-graded) bulk sp gr = 2.63 (SSD) absorp = 1.37% (OD) FM = 3.03 for MINUS 4	0.4 0.5 0.7	35.59 24.98 18.34	1.28 2.40 3.61	2.65 3.76 5.20	101 102 102	0.9 0.8 1.7

Note: (1) All prisms cured and stored in 73.4±2 F air at 100-percent RH.
*Prism compaction: hand-tamped unless noted otherwise.

1 Summation of Adjusted Average Strength Data for Hardened Mortars Incorporating Ideal-Graded Sands and Distilled

avg CMC, pcf	avg A/C, by wt	avg YIELD, cfsk	avg FLOW, %	avg EAC, %	avg UWP, pcf	*Adjusted Average DYE, psi x 10^6				*Adjusted Average FLS, psi				*A
						7d	28d	91d	364d	7d	28d	91d	364d	
26.18	2.26	3.59	104	1.6	138.01	---	3.92	---	---	---	1005	---	---	-
27.91	1.98	3.37	99	2.0	137.19	---	3.66	---	---	---	888	700	---	-
30.41	1.49	3.09	98	2.1	132.12	---	3.31	---	---	---	881	---	---	-
24.80	2.38	3.79	101	2.8	135.95	3.20	3.69	3.97	---	633	924	963	---	3
27.35	1.76	3.44	102	4.1	130.12	---	3.17	---	---	---	848	---	---	-
25.55	2.27	3.68	104	3.0	135.62	---	3.76	---	---	---	873	---	---	-
28.80	1.61	3.26	103	4.9	132.62	---	3.27	---	---	---	873	---	---	-
35.64	1.11	2.67	101	5.1	130.30	3.04	3.34	3.54	4.08	805	954	1049	881	4
24.73	2.04	3.82	100	8.7	126.04	2.71	3.04	3.14	3.31	544	749	825	925	[illegible]
16.28	3.29	5.78	102	12.9	119.01	1.99	2.34	2.38	2.75	313	476	557	609	[illegible]
35.59	1.28	2.65	101	0.9	134.35	3.38	3.84	4.20	4.53	749	939	933	889	[illegible]
24.98	2.40	3.76	102	0.8	138.18	3.08	3.82	4.11	4.29	518	803	877	873	[illegible]
18.34	3.61	5.20	102	1.7	137.96	2.59	3.42	3.84	4.07	334	593	731	754	[illegible]

.4±2 F air at 100-percent RH.
otherwise.

2

or Hardened Mortars Incorporating Ideal-Graded Sands and Distilled Water

Adjusted Average DYE, psi x 10^6				*Adjusted Average FLS, psi				*Adjusted Average MCS, psi			
d	28d	91d	364d	7d	28d	91d	364d	7d	28d	91d	364d
-	3.92	---	---	---	1005	---	---	---	5173	---	---
-	3.66	---	---	---	888	700	---	---	5685	---	---
-	3.31	---	---	---	881	---	---	---	5474	---	---
20	3.69	3.97	---	633	924	963	---	3649	4492	6110	---
-	3.17	---	---	---	848	---	---	---	4358	---	---
-	3.76	---	---	---	873	---	---	---	4784	---	---
-	3.27	---	---	---	873	---	---	---	4480	---	---
04	3.34	3.54	4.08	805	954	1049	881	4516	5958	7363	7568
71	3.04	3.14	3.31	544	749	825	925	2786	3900	4510	5310
99	2.34	2.38	2.75	313	476	557	609	1354	1976	2427	2849
38	3.84	4.20	4.53	749	939	933	889	4328	5963	8347	9310
03	3.82	4.11	4.29	518	803	877	873	2745	4732	6677	7454
59	3.42	3.84	4.07	334	593	731	754	1712	3229	4648	5263

Table IX. Final Summation of Adjusted Average Strength Data for Hardened M

Aggregate Identification	Nominal W/C, by wt	avg CMC, pcf	avg A/C, by wt	avg YIELD, cfsk	avg FLOW, %	avg EAC, %	avg UWP, pcf	*Adjusted Av	
								7d	2
AMBf (natural-graded)	0.3	52.05	0.53	1.81	97	3.0	134.22	**3.60	**3.
bulk sp gr = 2.60 (SSD)	0.4	34.76	1.15	2.70	104	6.6	128.04	3.20	3.
absorp = 3.72% (OD)	0.5	26.83	1.61	3.51	100	9.4	122.38	2.76	3.
FM = 2.44	0.7	19.26	2.34	4.88	101	11.2	117.23	2.10	2.
	0.9	15.39	2.93	6.11	100	10.9	114.71	1.60	2.
BJBf (natural-graded)	0.3	47.96	0.66	1.96	96	3.8	133.97	3.90	3.
bulk sp gr = 2.52 (SSD)	0.4	30.78	1.44	3.05	101	7.9	127.26	3.23	3.
absorp = 5.61% (OD)	0.5	23.78	2.04	3.95	100	9.8	123.25	2.56	2.
FM = 2.72	0.7	17.39	2.74	5.41	102	11.9	116.76	2.45	2.
	0.9	13.96	3.41	6.74	99	12.0	114.43	1.54	1.
GMRf (natural-graded)	0.3	48.35	0.72	1.94	103	2.8	136.61	4.23	4.
bulk sp gr = 2.64 (SSD)	0.4	28.43	1.85	3.30	98	9.4	128.58	3.26	3.
absorp = 1.97% (OD)	0.5	22.15	2.46	4.24	98	11.7	124.10	3.08	3.
FM = 2.57	0.7	16.26	3.38	5.78	99	12.9	119.74	2.14	2.
	0.9	12.89	4.34	7.30	99	12.8	117.85	1.70	2.
OO (graded per ASTM C109)	0.3	48.98	0.77	1.92	98	1.9	138.34	4.16	5.
bulk sp gr = 2.64 (SSD)	0.4	31.36	1.73	3.00	100	4.5	135.23	4.16	5.
absorp = 0.07% (OD)	0.5	24.34	2.42	3.86	99	5.5	132.60	4.45	3.
FM = 1.77	0.7	17.87	3.47	5.27	99	6.9	129.28	2.97	3.
	0.9	14.10	4.37	6.67	99	6.3	126.93	2.27	3.
SS (graded per 1954 Calif	0.4	32.44	1.66	2.90	100	2.3	137.94	3.50	4.
Hwy Div std specs)	0.5	24.08	2.52	3.90	101	5.1	133.71	3.24	3.
bulk sp gr = 2.63 (SSD)	0.7	16.63	3.81	5.65	102	6.9	129.75	2.62	3.
absorp = 1.37% (OD)	0.9	12.83	4.22	7.33	100	7.9	127.35	2.06	2.

Note: (1) All prisms cured and stored in 73.4±2 F air at 100-percent RH.
*Prism compaction: hand-tamped unless noted otherwise.
**Vibrated 2 minutes at 0.009-in. amplitude.

1

ata for Hardened Mortars Incorporating Natural-Graded Sands and Brackish Water

vg WP, cf	*Adjusted Average DYE, psi x 10^6				*Adjusted Average FLS, psi				*Adjusted Average MCS, psi			
	7d	28d	91d	364d	7d	28d	91d	364d	7d	28d	91d	364d
4.22	**3.60	**3.74	**4.13	**4.20	**1016	**1217	**1110	**939	**7552	**8588	**9934	11496
8.04	3.20	3.44	3.67	3.79	789	1018	1041	962	4854	6162	6826	7748
2.38	2.76	3.02	3.10	3.37	592	780	876	907	3055	4222	4862	5207
7.23	2.10	2.53	2.62	2.83	346	491	621	642	1563	2323	3038	3196
4.71	1.60	2.00	2.13	2.32	215	353	443	525	928	1464	1894	2178
3.97	3.90	3.87	4.08	4.38	1052	1148	1116	873	7217	9327	9802	9766
7.26	3.23	3.58	3.66	3.81	671	923	928	913	4108	5196	6316	7125
3.25	2.56	2.97	3.05	3.33	496	693	739	770	3197	4105	4765	5506
6.76	2.45	2.32	2.50	2.74	304	437	540	602	1440	2118	2683	3154
4.43	1.54	1.84	1.97	2.07	165	260	347	404	754	1208	1562	1826
6.61	4.23	4.47	4.63	4.47	980	1100	1096	963	7179	9570	10122	10919
8.58	3.26	3.62	4.13	3.82	603	815	912	978	3331	4450	5685	6673
24.10	3.08	3.19	3.46	3.63	478	666	730	817	2354	3446	4468	4922
19.74	2.14	2.69	2.79	2.84	280	412	551	618	1177	1858	2511	3018
7.85	1.70	2.07	2.55	2.36	196	237	372	398	629	1101	1420	1740
38.34	4.16	5.08	5.20	5.07	1015	1188	1199	1078	7081	9312	9898	11640
35.23	4.16	5.43	4.94	4.96	791	908	1002	922	4666	6351	7110	8313
32.60	4.45	3.63	4.57	4.96	551	723	829	816	3162	4873	5719	6348
29.28	2.97	3.96	3.80	4.26	343	508	604	556	1693	2680	3236	3610
26.93	2.27	3.13	3.72	3.84	221	349	468	435	976	1704	2137	2320
37.94	3.50	4.15	4.42	4.74	763	959	1045	904	4243	6061	7184	8634
33.71	3.24	3.75	4.07	4.35	560	781	939	872	3007	4375	5386	6319
29.75	2.62	3.17	3.42	3.67	335	509	633	633	1442	2442	3176	3686
27.35	2.06	2.68	2.87	3.12	230	380	509	503	950	1613	2108	2548

Table X. Final Summation of Adjusted Average Strength Data for Hardened Mortars Inc

Aggregate Identification	Nominal W/C, by wt	avg CMC, pcf	avg A/C, by wt	avg YIELD, cfsk	avg FLOW, %	avg EAC, %	avg UWP, pcf	*Adjusted Ave	
								7d	28
AMBf (natural-graded)	0.3	52.36	0.50	1.80	99	3.5	133.92	3.55	4.0
bulk sp gr = 2.60 (SSD)	0.4	34.64	1.15	2.72	99	7.3	127.57	3.25	3.5
absorp = 3.72% (OD)	0.5	26.74	1.61	3.52	101	10.0	122.03	2.72	3.4
FM = 2.44	0.7	19.56	2.30	4.81	104	10.5	118.21	2.14	2.4
	0.9	15.62	2.92	6.02	101	10.1	116.24	1.63	1.9
BJBf (natural-graded)	0.3	47.50	0.68	1.98	98	4.0	133.88	3.72	3.9
bulk sp gr = 2.52 (SSD)	0.4	31.28	1.43	3.01	102	8.5	127.88	3.40	3.8
absorp = 5.61% (OD)	0.5	23.07	2.06	4.07	98	12.3	120.30	2.62	2.8
FM = 2.72	0.7	17.39	2.74	5.41	98	12.1	116.74	2.17	2.3
	0.9	13.85	3.46	6.79	101	12.5	114.26	1.44	1.8
GMRf (natural-graded)	0.3	48.58	0.77	1.93	104	2.3	137.60	3.87	4.0
bulk sp gr = 2.64 (SSD)	0.4	28.25	1.85	3.32	99	10.1	127.84	3.52	3.7
absorp =1.97% (OD)	0.5	22.66	2.53	4.16	98	10.6	124.68	3.43	4.6
FM = 2.57	0.7	15.79	3.50	5.96	99	14.4	118.06	2.25	3.3
	0.9	12.34	4.46	7.62	101	14.0	116.85	1.80	2.2
OO (graded per ASTM C109)	0.3	49.35	0.73	1.91	96	2.1	138.26	4.29	5.2
bulk sp gr = 2.64 (SSD)	0.4	31.12	1.74	3.02	100	5.2	134.77	4.30	5.3
absorp = 0.07% (OD)	0.5	23.99	2.44	3.92	100	8.0	131.10	4.07	4.7
FM = 1.77	0.7	17.59	3.45	5.35	101	7.1	128.09	3.15	4.1
	0.9	14.23	4.31	6.61	101	6.3	127.13	2.35	3.2
SS (graded per 1954 Calif	0.3	51.86	0.61	1.81	95	1.3	138.38	3.79	4.7
Hwy Div std specs)	0.4	32.47	0.78	2.90	99	2.5	138.06	3.86	4.2
bulk sp gr = 2.63 (SSD)	0.5	24.35	2.43	3.86	101	4.6	134.75	3.39	4.0
absorp = 1.37% (OD)	0.7	16.96	3.84	5.55	100	5.3	132.15	2.96	3.4
FM = 2.88	0.9	13.66	4.70	6.88	101	5.8	129.71	2.29	2.9

Note: (1) All prisms cured and stored in 73.4±2 F air at 100-percent RH.
*Prism compaction: hand-tamped unless noted otherwise.

1

ened Mortars Incorporating Natural-Graded Sands and Sea Water

	*Adjusted Average DYE, psi x 10^6				*Adjusted Average FLS, psi				*Adjusted Average MCS, psi			
	7d	28d	91d	364d	7d	28d	91d	364d	7d	28d	91d	364d
2	3.55	4.02	4.21	4.34	1082	1139	1049	776	7541	8294	10120	10942
7	3.25	3.52	3.66	4.35	837	965	912	931	5077	6018	6689	7287
3	2.72	3.45	3.00	3.32	564	792	878	887	3295	4480	4749	5261
1	2.14	2.41	2.49	2.75	383	512	597	575	1798	2523	3028	3189
4	1.63	1.98	2.17	2.17	247	345	414	500	1106	1565	1943	1874
8	3.72	3.95	4.28	4.23	950	1053	1027	798	7615	8164	9053	10406
8	3.40	3.88	3.52	3.63	736	879	909	804	4003	5769	6509	6671
0	2.62	2.80	3.07	3.07	495	655	693	739	2978	4111	4506	4876
4	2.17	2.36	2.58	2.60	312	446	531	591	1529	2203	2752	3161
6	1.44	1.80	2.04	1.97	204	284	380	351	869	1338	1655	1899
0	3.87	4.03	4.47	4.49	1025	970	1085	862	7070	8864	10002	11268
4	3.52	3.74	3.60	3.94	648	831	952	888	3706	4968	5238	6276
8	3.43	4.63	3.28	3.44	481	649	778	785	2552	3555	4154	4711
6	2.25	3.32	2.95	3.04	283	420	300	463	1379	2055	2542	2465
5	1.80	2.20	2.33	2.35	168	235	352	324	726	1110	1398	1623
6	4.29	5.28	4.65	5.49	1239	1150	1081	1030	7776	8928	10807	11947
7	4.30	5.36	4.72	4.75	769	951	994	870	4881	6306	7098	7392
0	4.07	4.74	4.56	4.75	625	707	845	782	3558	4656	5792	6071
9	3.15	4.11	4.05	4.25	379	550	619	590	1988	2876	3452	3692
3	2.35	3.26	3.09	3.99	252	361	459	441	1182	1818	2260	2404
8	3.79	4.74	4.37	4.64	1097	1091	1016	829	6624	8337	9411	11099
6	3.86	4.20	4.06	4.66	753	900	953	858	5502	6365	7575	8683
5	3.39	4.04	4.15	4.47	689	792	885	825	3460	4766	5663	6348
5	2.96	3.43	3.53	3.76	426	591	685	667	2013	3009	3559	4262
1	2.29	2.92	2.93	3.19	257	381	462	488	1410	1722	2107	2700

preview of the experimental reliability that could be anticipated in the regular mix series and thus were useful in establishing information that subsequently served as a guide in the design of those mortar mixtures comprising the major portion of the Group B Schedule. As explained in Section 8, the initial-plot series also served to demonstrate the desirability of the water-cement ratio values used in this investigation.

Each plotted point shown on any of the graphs in the final-plot series represents the numerical average of: (1) two companion mixes, at least; (2) six or seven companion mixes, generally; or (3) eighteen companion mixes, at most. Each mix was the source of four prismatic test specimens. For any one sand, type of water, water-cement ratio, and flow within ± 5 percent, each mix was equal in all respects to its companion mixes.

Graphical representations of the correlations listed in Table I involve various combinations of dependent and independent variables. For example, Correlation 1c-a' in terms of graphics entails the following considerations:

(1)	[type of water water-cement ratio]	controlled variables
	[aggregate derivation]	parameter
(2)	[water-cement ratio aggregate derivation]	controlled variables
	[type of water]	parameter
(3)	[aggregate derivation type of water]	controlled variables
	[water-cement ratio]	parameter

These combinations, of course, indicate the necessity of plotting three graphs to attain maximum correlation. Figures 16 and 17 depict, respectively, graphical representations (1) and (3) defined above. Representation (2) is found insignificant and therefore is meaningless with respect to detection of trends. This example serves to illustrate that complete graphical representations are not requisite for each and every correlation listed in Table I.[5.3]

The original plans for this research provided for two additional gradation categories; specifically, these were gradation blends conforming to ASTM Designation C33-54T and arbitrary gap-gradations. Scarcity of certain coral sands and lack of time dictated omission of these two additional features, and consequently the correlations apply only to mortar mixes that incorporate natural or ideal gradations of certain sands.

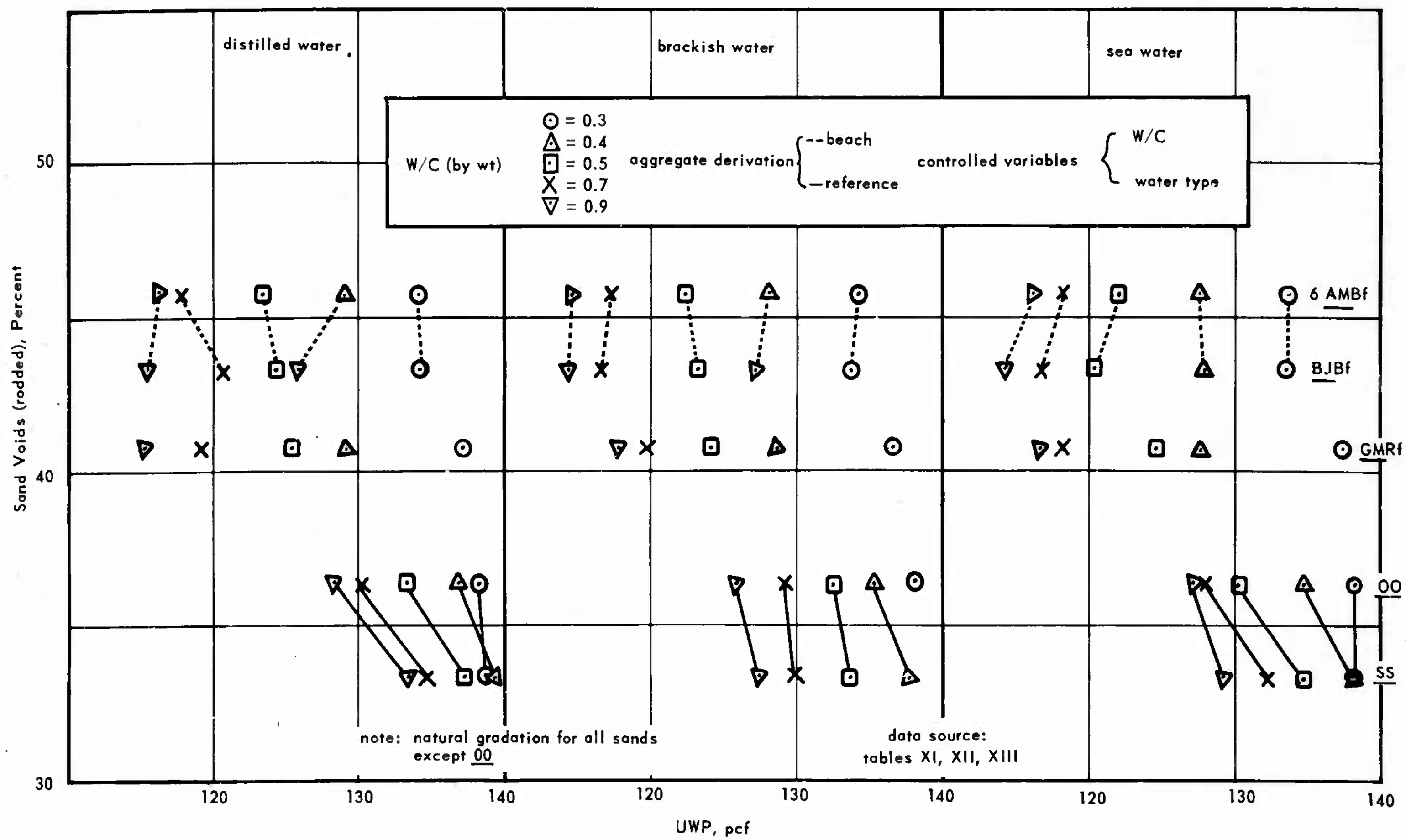


Figure 16. Correlation 1c-a'.

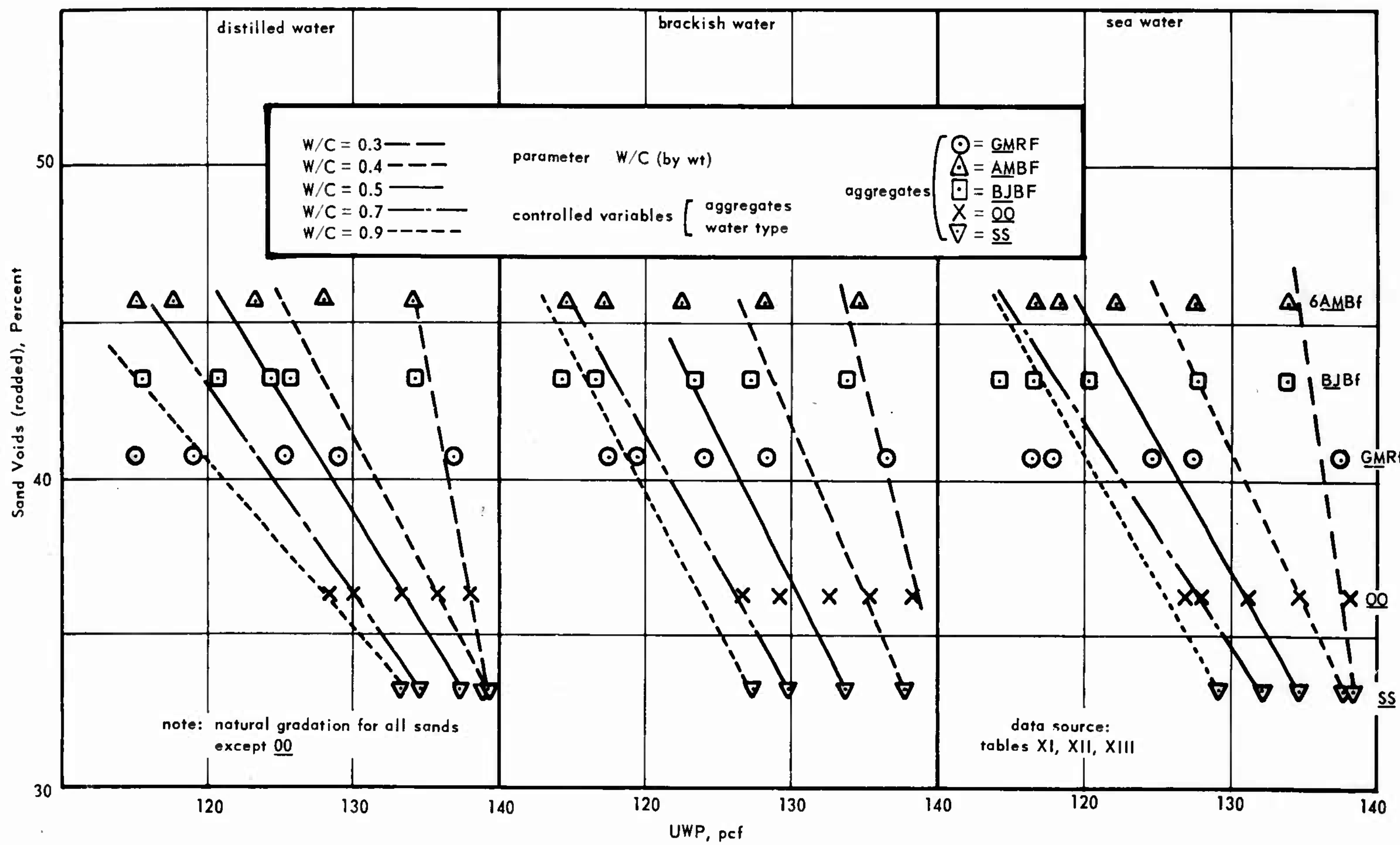


Figure 17. Correlation 1c-a'.

All ideal-graded sands in this investigation conformed to the Size 4 distribution pattern exhibited in Table XVII (part of Appendix I). As a reference gradation, the Weymouth theory is considered superior to the other ideal-curve theories, although the latter sometimes are useful in creating similar gradations by purely empirical methods. The superiority of the Weymouth theory lies in its rational approach and in its adaptability to mathematical analysis.

The subheadings appearing in Sections 19 and 21 refer to the analytical relationships shown in Table I; the factors involved in these relationships are presented in Sections 1 and 2.

The graphs comprising Figures 19 to 104, inclusive, constitute the best currently available criteria for evaluating the strength characteristics of any particular coral mortar investigated in this study.

Analyses of the test data indicate that meaningful graphical representations of certain correlations cannot be established. Explanations concerning omissions of this type also are given in Sections 2 and 18. Such omissions are distinct from correlations found insignificant, and are so indicated in Table I.

CHAPTER 5 END NOTES

5.1 Columnar headings, from left to right, were: (1) Nominal W/C, by wt; (2) Corrected W/C, by wt; (3) Mix Number; (4) Rupture Modulus, psi; (5) Compressive Strength, psi; (6) Dynamic Elastic Modulus, psi; (7) Bulk Density, lb per cu ft mortar; (8) Flow, percent; and (9) Air Content, percent. Characteristics (4), (5), and (6) applied to each of the four test ages. Characteristic (7) applied at age 24 hr and also at each of the four test ages.

5.2 Dynamic elastic modulus, rupture modulus or flexural strength, and compressive strength values prior to adjustment.

5.3 In Group 2, for instance, Correlations 2c-a' and 2h-a' are not represented graphically.

Part II. PHYSICAL PROPERTIES

Chapter 6

MORTARS IN THE PLASTIC STATE

18. PRELIMINARY CONSIDERATIONS

The flow values of all mortars were confined intentionally to a very narrow range and any occasional variations therefrom were insignificant. Correlations between flow and cement content (also between flow and aggregate-cement ratio)[6.1] thus are impossible. This applies not only to mortar mixes of equal gradation. Changes from natural to ideal gradation reflected corresponding changes in cement content; the latter change in turn caused only minor variations in the flow values of the resultant mortars; in those instances, too, the above correlations cannot be made.

The cement content values had been determined by experimentation in the preliminary series of mixes. These coral mortar experiments provided 31 mixes involving GMRf[6.2] and 42 mixes involving BJBf[6.2]. With regard to reference mortars, these initial designs provided 20 mixes involving OO[6.2]. Experimental results obtained with 88 other reference mortars, which involved SS[6.2] exclusively and which were not part of the preliminary series of mixes, were intended for correlation with data that would have resulted from the experimental concrete mix designs contemplated as part of the Group C Schedule of tests.

19. INTERPRETATION OF OBSERVATIONS

Correlation 1a-a'.

Graphical representation of this relationship is satisfied by Correlation 1c-a', shown in Figures 16 and 17. It is apparent that water type exerts very little, if any, influence upon the UWP[6.3] (unit weight of mortar in the plastic state) characteristics of coral or reference mortars.

Correlation 1b-a'.

Examination of Figure 18 discloses the change in rate of variation in coral mortar UWP with increase in FM (fineness modulus of the sand), regardless of geographical source, for those cases involving natural-graded coral sands that are considered as R- or B-derived (respectively, reef or beach sources). When the W/C (water-cement ratio) is 0.3, all investigated mortars exhibit the same orders of UWP magnitude (regardless of water type, regardless of whether classified as reference or coral sands, and regardless of whether or nor their gradation is natural).

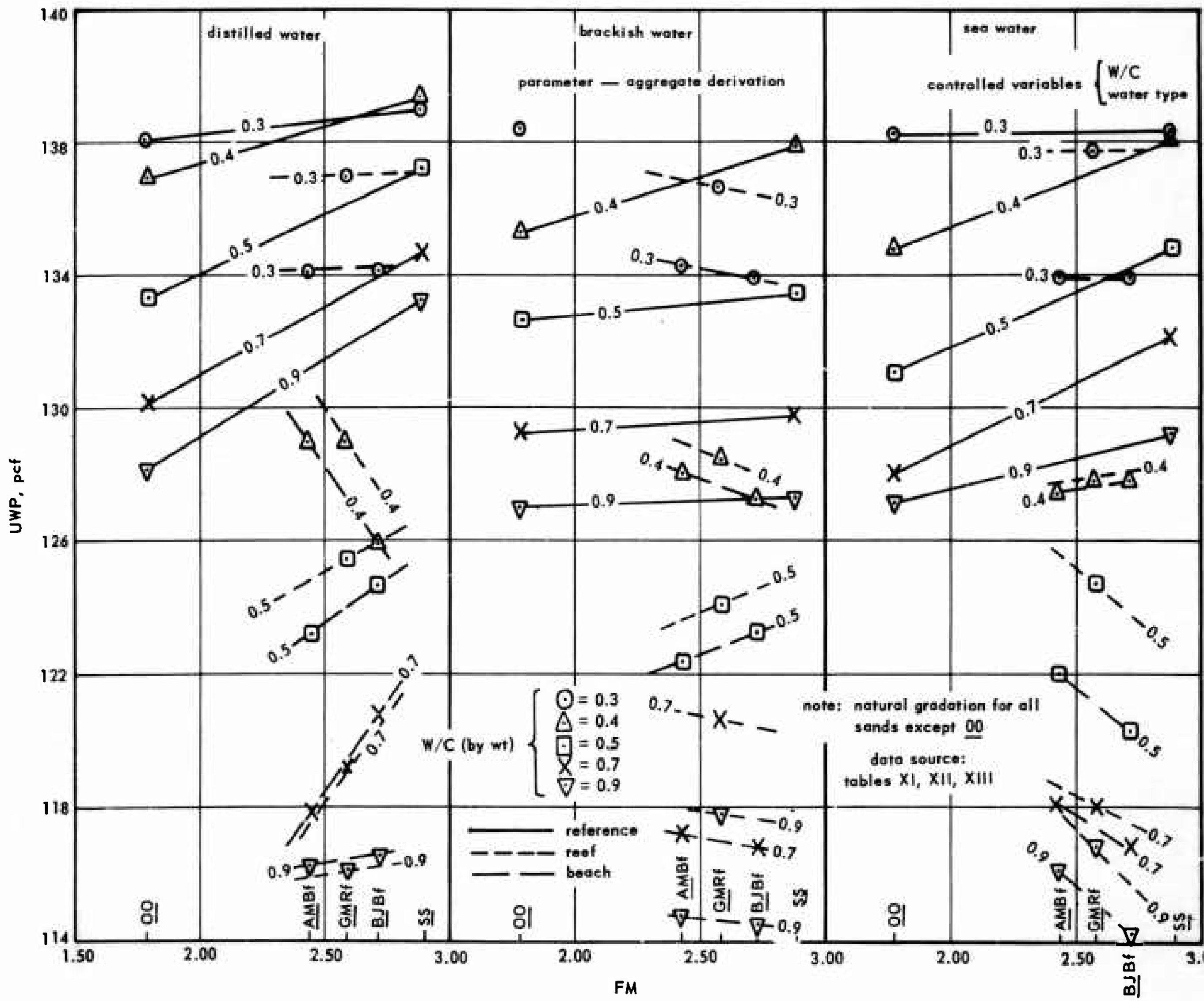


Figure 18. Correlation 1b-a'.

When sea water is used in coral mortars the rates of decreasing UWP, with increasing FM, are rather stable for mixes of W/C > 0.5; for coral mortars of W/C < 0.5, UWP remains constant regardless of FM variation. The use of sea water in reference mortars, however, causes the former of these two trends to reverse (i.e., UWP increases with increase in FM).

The use of brackish instead of sea water in coral mortars merely reflects a lesser rate of variation in UWP with change in FM and all other features remain approximately equal.

The use of distilled water in reference mortars, as compared with sea water, causes no appreciable change in rate nor in amount of UWP as FM increases from 1.50 to about 3.00.

Judging by Figure 18, a W/C of 0.4 or 0.5 appears to be the key to the manner in which the coral mortar UWP varies with changing values of FM.

Correlation 1c-a'.

As shown in Figure 16, the UWP of reference mortars decreases not more than 10 percent as the W/C increases from 0.3 to 0.9 (regardless of water type), within the percent voids range indicated. It is logical to assume, based upon the evidence in Figure 16, the UWP of reference mortars would drop considerably as the percent voids increases. Coral mortars, fabricated with B-derived coral sands, behave in a relatively unpredictable fashion. As a general rule, a variation of 5 or less percent voids has no sensible effect upon UWP of mortars incorporating coral beach sands and any type of water; whether or not this rule applies also to R-derived sand mortars is problematical.

With W/C as the parameter, as in Figures 17 and 19, it is apparent that variation of UWP, with changes in percent voids, depends considerably upon the wetness of the cement paste regardless of water type employed. It is obvious, too, that SS sand is desirable for attaining mortars that are more or less stable with respect to UWP.

Correlation 1d-a'.

Not evaluated for reasons stated in Section 2.

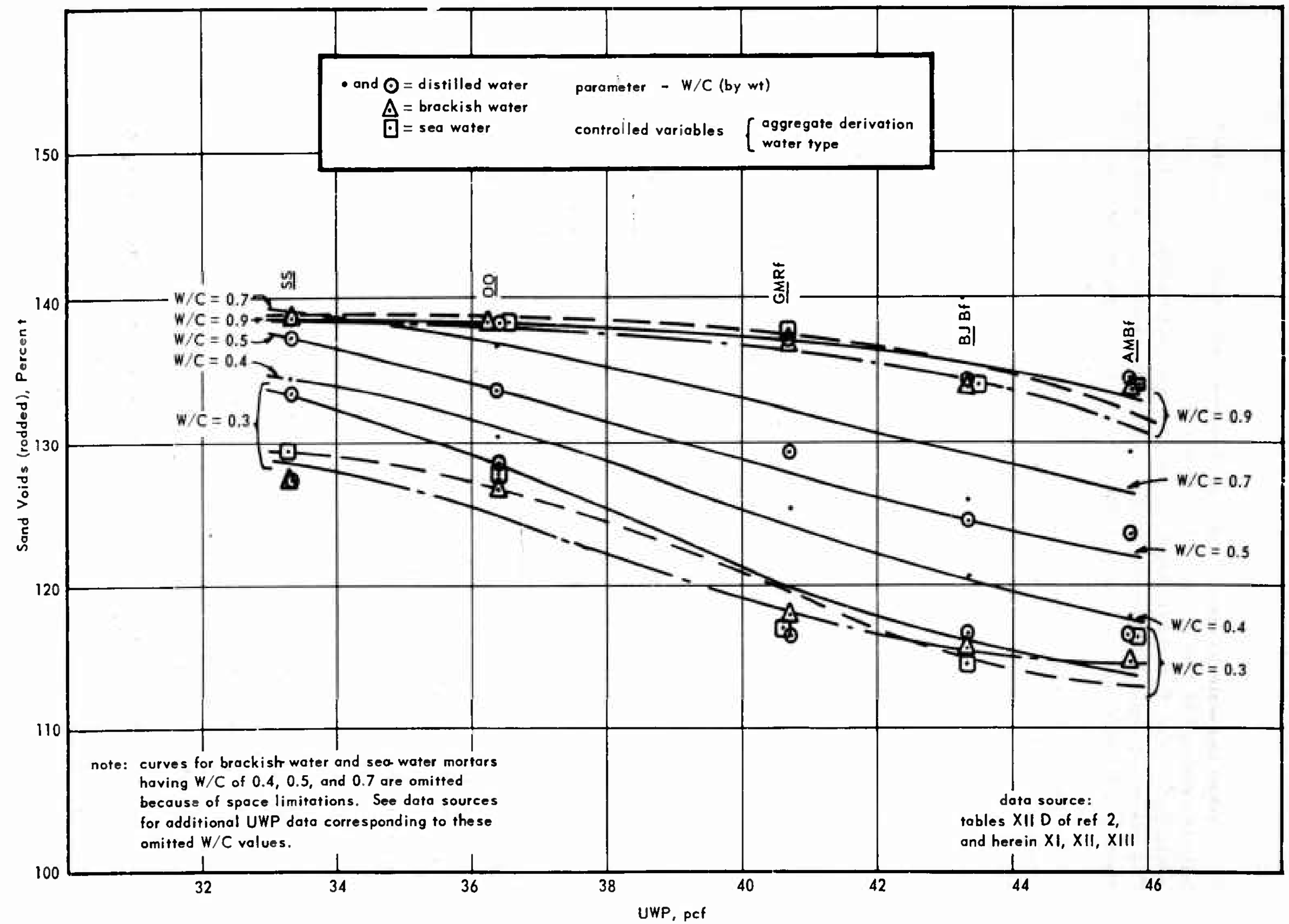


Figure 19. Correlation 1c-a'.

Correlation 1e-a'.

In the case of mixes having high W/C, the curves in Figure 20 indicate that mortars fabricated with coral reef sands exhibit generally about 4 percent more EAC (entrained-air content of mortar in the plastic state) than mortars which incorporate coral beach sands and about 8 percent more EAC than mortars made with reference sands; this trend holds true regardless of water type. At low W/C, regardless of mix water employed, the percent EAC appears to be practically unaffected by type of fine aggregate derivation.

Figure 21 is another version of the same trend and reveals the curves for all investigated values of the W/C parameter when distilled water is used in the mortar mixes. Only two or three W/C values comprise the families of curves shown for the cases of brackish or sea water mixes; these families are sufficient to illustrate the facts stated above with reference to Figure 20.

When the test data are plotted in a fashion such that the parameter is mix water, as illustrated in Figure 22, it is obvious that type of water exerts a minor effect upon the relationship between EAC and UWP. Figure 22 also illustrates that the type of sand has no particular effect upon the relationship when the W/C is low in value.

Correlation 2a-a'.

Tables XI, XII, and XIII disclose that the least variable percent flow is attainable with distilled water regardless of the derivation of sand involved. When sea water is employed the data indicate that generally the range in variation of flow, using 100 percent as the reference value, is nearly twice that exhibited by mortars incorporating distilled water; this is valid regardless of sand derivation. If the range in flow variation of each mortar mix is considered in computing the average variations pertinent to types of mix water, it becomes apparent that the average range in flow variation for distilled-water mixes is 3 percent, for brackish-water mixes 4 percent, and for sea-water mixes 5 percent; this fact is illustrated in Figure 23 wherein W/C values of 0.3 and 0.9 are omitted for convenience only.

Correlations 2b-a', 2c-a', 2d-a' and 2e-a'.

Not evaluated for reasons stated in Section 2.

Correlation 2f-a'.

See Section 13 and last sentence below concerning Correlation 2g-a'.

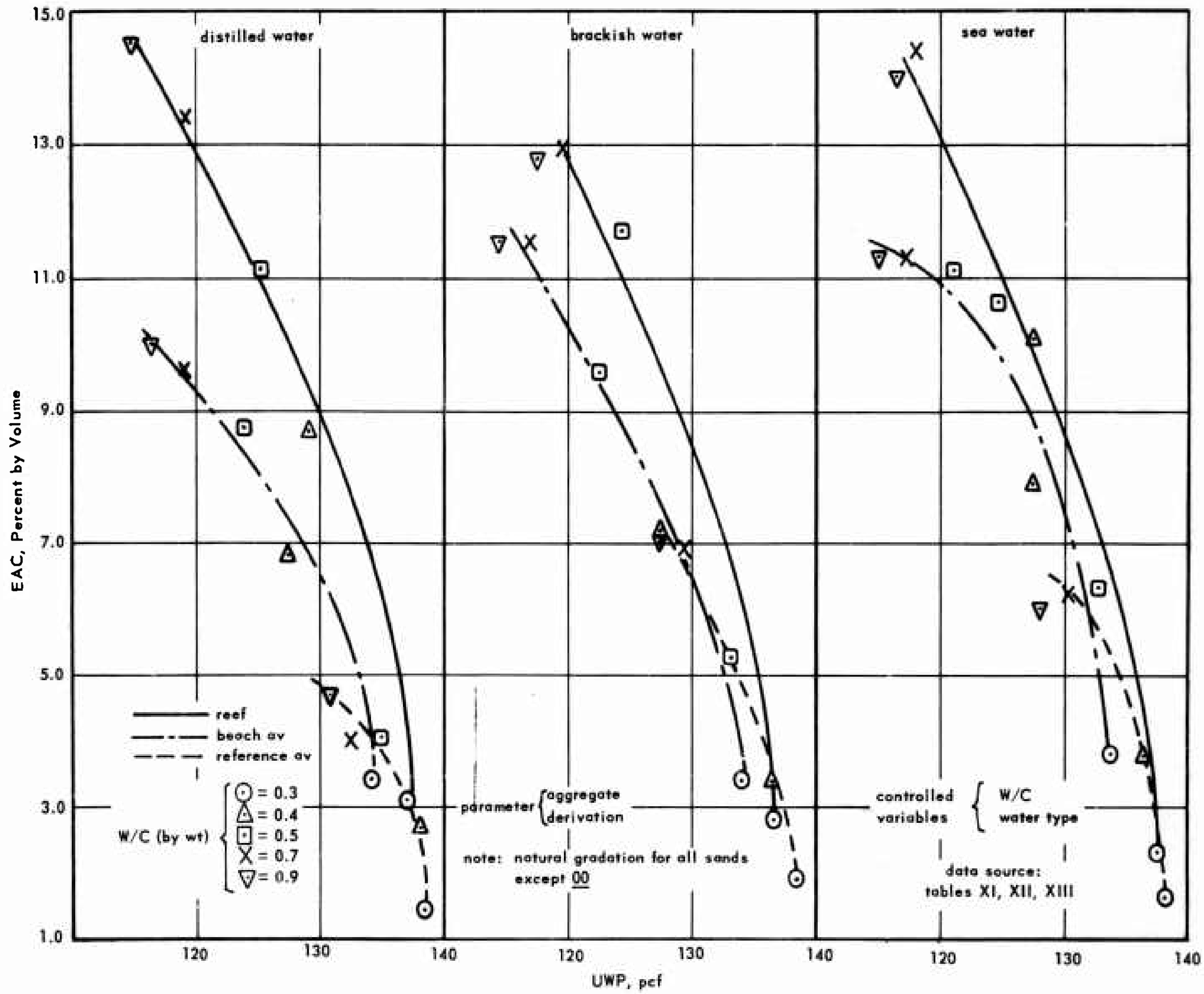


Figure 20. Correlation 1e-a'.

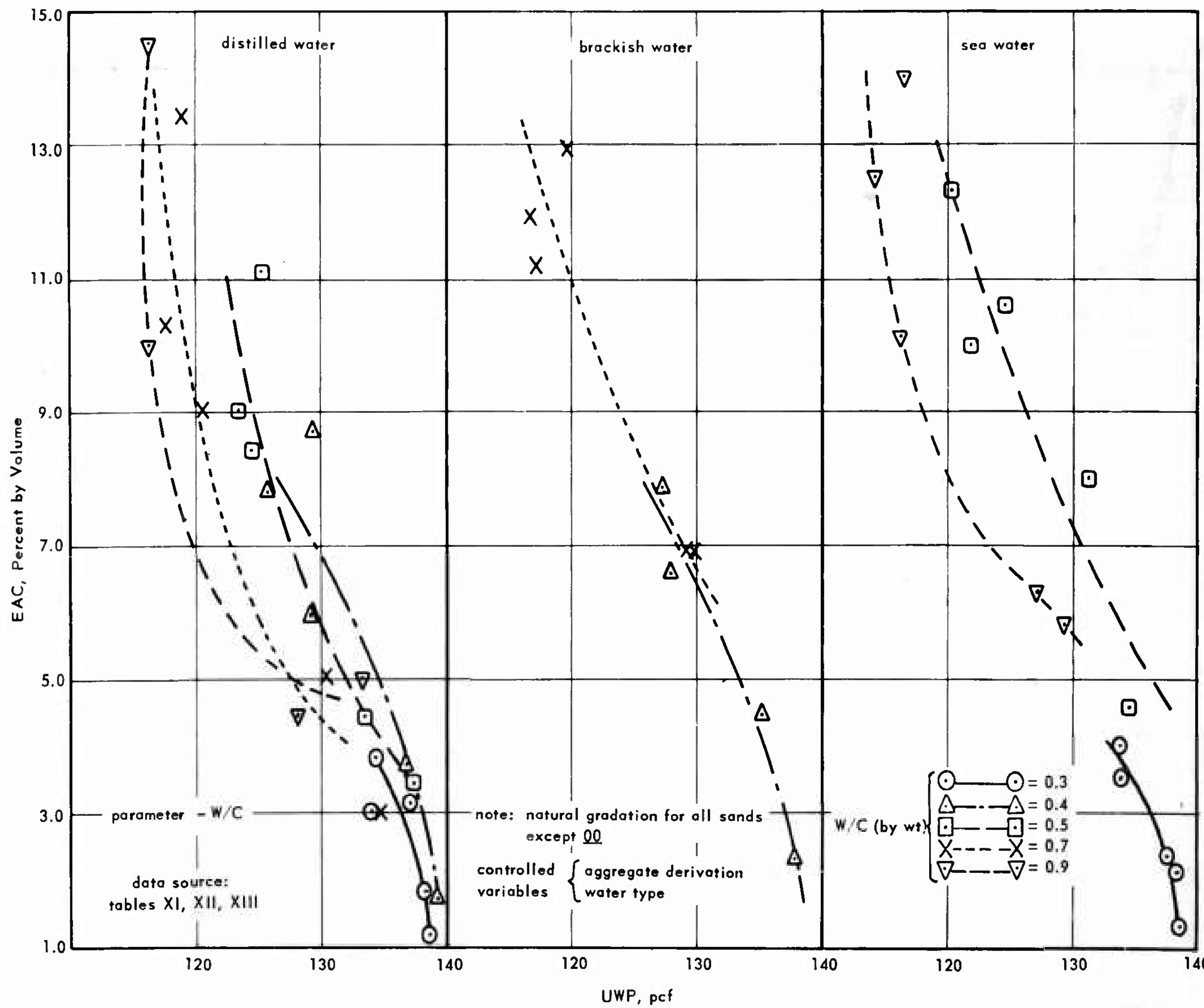


Figure 21. Correlation le-a'.

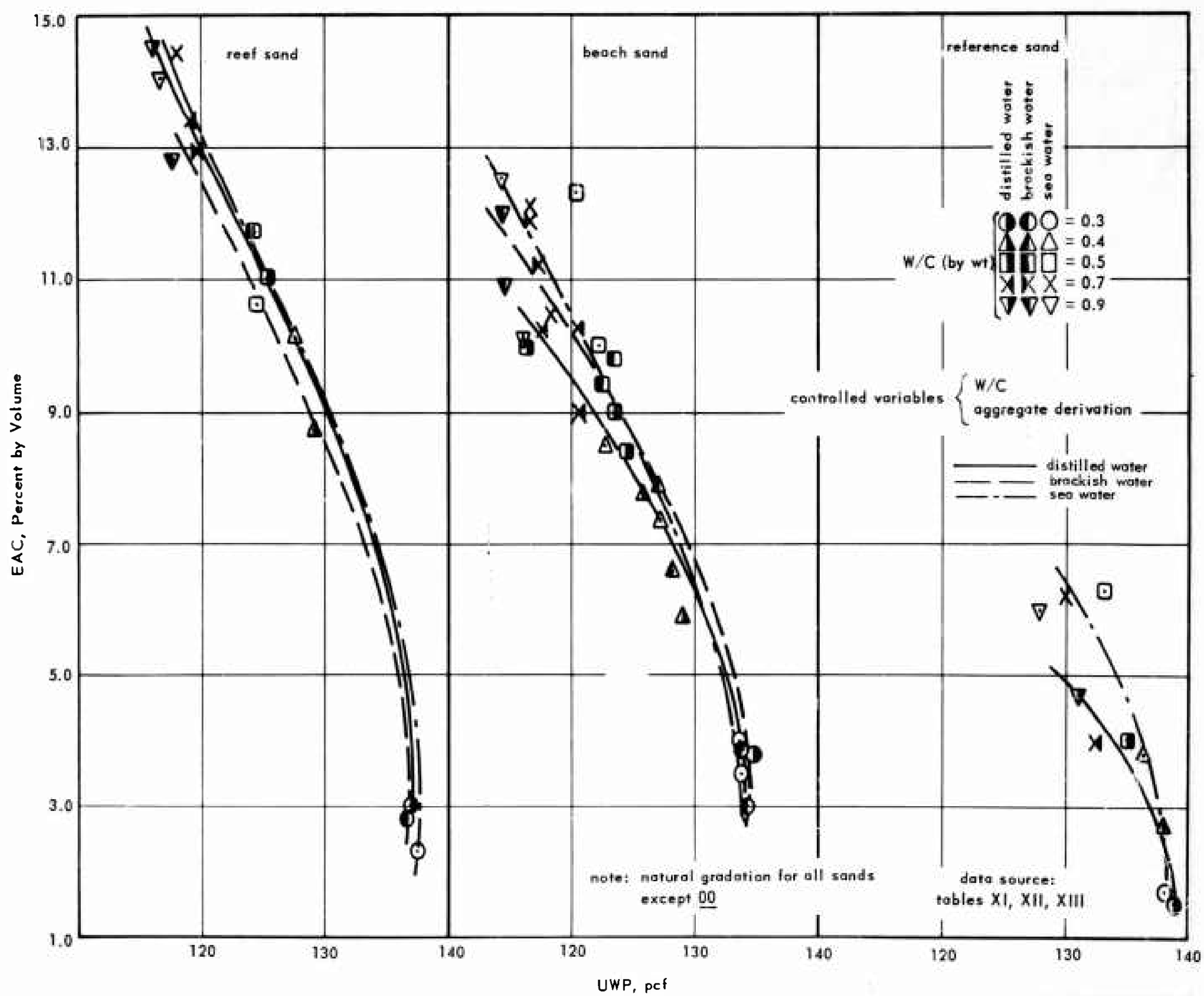


Figure 22. Correlation le-a'.

Table XI. Unit Weight of Plastic Mortars and Bulk Density of Hardened Mortars Incorpora

Aggregate Identification	Nominal W/C, by wt	avg CMC, pcf	avg A/C, by wt	avg YIELD, cfsk	avg FLOW, %	avg EAC, %	avg UWP, pcf	
								24h
AMBf (natural-graded)	0.3	52.42	0.50	1.79	97	3.0	134.06	135.17
bulk sp gr = 2.60 (SSD)	0.4	34.91	1.16	2.69	98	5.9	129.07	129.77
absorp = 3.72% (OD)	0.5	27.04	1.62	3.48	98	9.0	123.39	126.17
FM = 2.44	0.7	19.46	2.30	4.83	100	10.3	117.86	121.75
	0.9	15.49	3.05	6.07	98	10.0	116.26	121.00
BJBf (natural-graded)	0.3	46.17	0.75	2.04	97	3.7	134.20	134.55
bulk sp gr = 2.52 (SSD)	0.4	29.57	1.53	3.18	98	8.8	125.81	128.75
absorp = 5.61% (OD)	0.5	21.86	2.58	4.30	100	8.5	124.54	127.23
FM = 2.72	0.7	15.78	3.56	5.96	98	9.0	120.27	124.24
	0.9	12.35	4.53	7.61	100	11.2	116.57	121.12
BJBf (natural-graded)	0.3	35.56	0.68	1.96	97	3.6	134.76	134.63
ditto except vibrated	0.4	30.85	1.51	3.05	98	6.6	129.13	130.49
2 minutes at 0.009-in.	0.5	24.30	1.98	3.87	101	8.4	125.00	130.44
amplitude	0.7	18.23	2.67	5.16	98	9.0	120.81	126.98
	0.9	14.74	3.27	6.38	98	9.4	118.35	123.82
ENPcf (natural-graded)	0.5	21.11	2.54	4.45	97	8.7	126.48	130.80
bulk sp gr = 2.40 (SSD)								
absorp = 5.10% (OD)								
FM = 3.89 for MINUS 4								
GMRf (natural-graded)	0.3	48.35	0.74	1.94	99	3.1	137.03	137.01
bulk sp gr = 2.64 (SSD)	0.4	29.00	1.81	3.24	99	8.7	129.14	131.15
absorp = 1.97% (OD)	0.5	21.86	2.58	4.30	98	11.1	125.42	125.93
FM = 2.57	0.7	15.78	3.56	5.96	98	13.4	119.20	120.95
	0.9	12.35	4.53	7.61	99	14.5	116.12	118.66
OO (graded per ASTM C109)	0.3	46.52	0.85	2.02	98	1.8	138.02	139.44
bulk sp gr = 2.64 (SSD)	0.4	32.04	1.83	2.94	101	3.7	136.90	138.69
absorp = 0.07% (OD)	0.5	23.55	2.56	3.99	101	4.4	133.36	136.06
FM = 1.77	0.7	17.45	3.54	5.38	100	5.0	130.30	133.80
	0.9	14.11	4.38	6.67	99	4.4	128.38	132.08
SS (graded per Calif Hwy	0.3	51.02	0.65	1.84	98	1.1	138.98	139.88
Div 1954 std specs)	0.4	32.76	1.66	2.87	100	1.7	139.28	140.90
bulk sp gr = 2.63 (SSD)	0.5	25.74	2.30	3.65	100	3.5	137.37	140.85
absorp = 1.37% (OD)	0.7	18.26	3.51	5.15	98	3.0	134.61	137.94
FM = 2.88	0.9	13.32	4.44	7.05	101	5.0	133.21	136.96
SS (graded per Calif Hwy	0.4	32.37	1.67	2.91	101	2.5	137.47	142.06
Div 1954 std specs)	0.5	24.53	2.44	3.83	98	3.5	136.01	139.96
ditto except vibrated	0.7	17.88	3.58	5.26	96	3.6	133.36	139.72
2 minutes at 0.009-in.	0.9	13.68	4.65	6.87	100	5.5	129.05	138.38
amplitude								

*Prism compaction: hand-tamped unless noted otherwise.
Note: (1) All BUD prisms cured and stored in 73.4±2 F air at 100-percent RH.

Plastic Mortars and Bulk Density of Hardened Mortars Incorporating Distilled Water

Nominal W/C, by wt	avg CMC, pcf	avg A/C, by wt	avg YIELD, cfsk	avg FLOW, %	avg EAC, %	avg UWP, pcf	*avg BUD, pcf				
							24h	7d	28d	91d	364d
0.3	52.42	0.50	1.79	97	3.0	134.06	135.17	134.70	136.11	136.20	137.52
0.4	34.91	1.16	2.69	98	5.9	129.07	129.77	129.07	129.94	130.09	131.75
0.5	27.04	1.62	3.48	98	9.0	123.39	126.17	125.83	126.20	126.29	128.03
0.7	19.46	2.30	4.83	100	10.3	117.86	121.75	122.59	122.21	122.23	123.72
0.9	15.49	3.05	6.07	98	10.0	116.26	121.00	120.84	120.97	121.08	121.95
0.3	46.17	0.75	2.04	97	3.7	134.20	134.55	135.17	135.48	135.94	137.05
0.4	29.57	1.53	3.18	98	8.8	125.81	128.75	129.12	128.48	129.22	130.68
0.5	21.86	2.58	4.30	100	8.5	124.54	127.23	127.32	126.69	127.69	129.96
0.7	15.78	3.56	5.96	98	9.0	120.27	124.24	124.69	125.52	125.19	125.43
0.9	12.35	4.53	7.61	100	11.2	116.57	121.12	123.21	122.34	120.21	123.53
0.3	35.56	0.68	1.96	97	3.6	134.76	134.63	135.17	136.10	140.78	137.59
0.4	30.85	1.51	3.05	98	6.6	129.13	130.49	128.16	131.58	131.43	132.43
0.5	24.30	1.98	3.87	101	8.4	125.00	130.44	129.98	132.05	131.43	130.55
0.7	18.23	2.67	5.16	98	9.0	120.81	126.98	127.23	127.85	128.47	128.36
0.9	14.74	3.27	6.38	98	9.4	118.35	123.82	122.92	124.37	125.62	126.15
0.5	21.11	2.54	4.45	97	8.7	126.48	130.80	--	129.82	129.00	--
0.3	48.35	0.74	1.94	99	3.1	137.03	137.01	137.49	138.27	139.32	140.19
0.4	29.00	1.81	3.24	99	8.7	129.14	131.15	131.31	131.28	131.31	133.06
0.5	21.86	2.58	4.30	98	11.1	125.42	125.93	126.92	126.90	127.54	128.00
0.7	15.78	3.56	5.96	98	13.4	119.20	120.95	122.22	121.82	122.34	122.88
0.9	12.35	4.53	7.61	99	14.5	116.12	118.66	119.86	118.88	120.34	120.80
0.3	46.52	0.85	2.02	98	1.8	138.02	139.44	140.90	140.78	141.03	142.12
0.4	32.04	1.83	2.94	101	3.7	136.90	138.69	138.68	140.53	140.21	140.30
0.5	23.55	2.56	3.99	101	4.4	133.36	136.06	136.39	136.29	136.42	137.91
0.7	17.45	3.54	5.38	100	5.0	130.30	133.80	134.05	134.55	134.42	135.32
0.9	14.11	4.38	6.67	99	4.4	128.38	132.08	132.30	132.80	132.55	132.82
0.3	51.02	0.65	1.84	98	1.1	138.98	139.88	140.16	141.24	141.24	142.30
0.4	32.76	1.66	2.87	100	1.7	139.28	140.90	140.31	141.40	141.96	142.30
0.5	25.74	2.30	3.65	100	3.5	137.37	140.85	139.94	140.46	140.50	141.40
0.7	18.26	3.51	5.15	98	3.0	134.61	137.94	138.13	138.42	139.14	139.40
0.9	13.32	4.44	7.05	101	5.0	133.21	136.96	136.26	136.42	136.99	137.50
0.4	32.37	1.67	2.91	101	2.5	137.47	142.06	140.65	140.88	141.93	142.95
0.5	24.53	2.44	3.83	98	3.5	136.01	139.96	139.40	139.41	140.96	141.88
0.7	17.88	3.58	5.26	96	3.6	133.36	139.72	138.28	139.38	139.94	141.55
0.9	13.68	4.65	6.87	100	5.5	129.05	138.38	138.60	137.91	139.08	138.90

unless noted otherwise.
and stored in 73.4±2 F air at 100-percent RH.

Table XII. Unit Weight of Plastic Mortars and Bulk Density of Hardened Mortars Inco

Aggregate Identification	Nominal W/C, by wt	avg CMC, pcf	avg A/C, by wt	avg YIELD, cfsk	avg FLOW, %	avg EAC, %	avg UWP, pcf	24h
AMBf (natural-graded)	0.3	52.05	0.53	1.81	97	3.0	134.22	**134.78
bulk sp gr = 2.60 (SSD)	0.4	34.76	1.15	2.70	104	6.6	128.04	130.00
absorp = 3.72% (OD)	0.5	26.83	1.61	3.51	100	9.4	122.38	124.96
FM = 2.44	0.7	19.26	2.34	4.88	101	11.2	117.23	121.57
	0.9	15.39	2.93	6.11	100	10.9	114.71	118.31
BJBf (natural-graded)	0.3	47.96	0.66	1.96	96	3.8	133.97	134.66
bulk sp gr = 2.52 (SSD)	0.4	30.78	1.44	3.05	101	7.9	127.26	129.85
absorp = 5.61% (OD)	0.5	23.78	2.04	3.95	100	9.8	123.25	124.74
FM = 2.72	0.7	17.39	2.74	5.41	102	11.9	116.76	120.65
	0.9	13.96	3.41	6.74	99	12.0	114.43	118.82
GMRf (natural-graded)	0.3	48.35	0.72	1.94	103	2.8	136.61	137.08
bulk sp gr = 2.64 (SSD)	0.4	28.43	1.85	3.30	98	9.4	128.58	131.23
absorp = 1.97% (OD)	0.5	22.15	2.46	4.24	98	11.7	124.10	125.99
FM = 2.57	0.7	16.26	3.38	5.78	99	12.9	119.74	122.56
	0.9	12.89	4.34	7.30	99	12.8	117.85	119.31
OO (graded per ASTM C109)	0.3	48.98	0.77	1.92	98	1.9	138.34	139.09
bulk sp gr = 2.64 (SSD)	0.4	31.36	1.73	3.00	100	4.5	135.23	138.13
absorp = 0.07% (OD)	0.5	24.34	2.42	3.86	99	5.5	132.60	135.06
FM = 1.77	0.7	17.87	3.47	5.27	99	6.9	129.28	132.15
	0.9	14.10	4.37	6.67	99	6.3	126.93	130.60
SS (graded per Calif Hwy Div 1954 std specs)	0.4	32.44	1.66	2.90	100	2.3	137.94	140.27
bulk sp gr = 2.63 (SSD)	0.5	24.08	2.52	3.90	101	5.1	133.71	137.20
absorp = 1.37% (OD)	0.7	16.63	3.81	5.65	102	6.9	129.75	134.94
FM = 2.88	0.9	12.83	4.22	7.33	100	7.9	127.35	131.66

Note: (1) All BUD prisms cured and stored in 73.4±2 F air at 100-percent RH.
*Prism compaction: hand-tamped unless noted otherwise.
**Vibrated 2 minutes at 0.009-in. amplitude.

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Plastic Mortars and Bulk Density of Hardened Mortars Incorporating Brackish Water

avg CMC, pcf	avg A/C, by wt	avg YIELD, cfsk	avg FLOW, %	avg EAC, %	avg UWP, pcf	*avg BUD, pcf				
						24h	7d	28d	91d	364d
52.05	0.53	1.81	97	3.0	134.22	**134.78	**135.95	**136.10	**134.76	**138.00
34.76	1.15	2.70	104	6.6	128.04	130.00	130.18	130.34	131.43	133.29
26.83	1.61	3.51	100	9.4	122.38	124.96	124.74	124.42	125.36	127.40
19.26	2.34	4.88	101	11.2	117.23	121.57	121.62	121.94	121.80	123.18
15.39	2.93	6.11	100	10.9	114.71	118.31	117.57	119.28	118.97	121.12
47.96	0.66	1.96	96	3.8	133.97	134.66	134.92	135.92	136.29	137.14
30.78	1.44	3.05	101	7.9	127.26	129.85	129.36	129.56	130.48	131.00
23.78	2.04	3.95	100	9.8	123.25	124.74	125.20	125.83	125.62	126.90
17.39	2.74	5.41	102	11.9	116.76	120.65	121.78	122.09	121.31	123.30
13.96	3.41	6.74	99	12.0	114.43	118.82	119.44	119.36	120.38	121.67
48.35	0.72	1.94	103	2.8	136.61	137.08	138.49	138.49	138.70	140.15
28.43	1.85	3.30	98	9.4	128.58	131.23	129.56	131.43	132.67	133.34
22.15	2.46	4.24	98	11.7	124.10	125.99	127.07	126.29	127.38	128.70
16.26	3.38	5.78	99	12.9	119.74	122.56	124.71	123.08	123.20	124.59
12.89	4.34	7.30	99	12.8	117.85	119.31	120.64	120.01	121.26	121.98
48.98	0.77	1.92	98	1.9	138.34	139.09	140.28	140.53	140.70	141.64
31.36	1.73	3.00	100	4.5	135.23	138.13	138.04	138.53	139.53	139.66
24.34	2.42	3.86	99	5.5	132.60	135.06	135.42	135.92	136.54	136.90
17.87	3.47	5.27	99	6.9	129.28	132.15	132.52	132.84	133.30	132.83
14.10	4.37	6.67	99	6.3	126.93	130.60	130.81	131.06	130.93	131.80
32.44	1.66	2.90	100	2.3	137.94	140.27	140.00	140.09	140.86	142.32
24.08	2.52	3.90	101	5.1	133.71	137.20	136.57	136.74	137.22	138.60
16.63	3.81	5.65	102	6.9	129.75	134.94	133.15	133.72	134.40	134.88
12.83	4.22	7.33	100	7.9	127.35	131.66	131.27	131.50	131.86	133.45

l in 73.4$\pm$2 F air at 100-percent RH.
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Table XIII. Unit Weight of Plastic Mortars and Bulk Density of Hardened Mortars Incorpo

Aggregate Identification	Nominal W/C, by wt	avg CMC, pcf	avg A/C, by wt	avg YIELD, cfsk	avg FLOW, %	avg EAC, %	avg UWP, pcf	24h	7
AMBf (natural-graded)	0.3	52.36	0.50	1.80	99	3.5	133.92	135.40	135
bulk sp gr = 2.60 (SSD)	0.4	34.64	1.15	2.72	99	7.3	127.57	128.94	128
absorp = 3.72% (OD)	0.5	26.74	1.61	3.52	101	10.0	122.03	124.19	124
FM = 2.44	0.7	19.56	2.30	4.81	104	10.5	118.21	121.70	122
	0.9	15.62	2.92	6.02	101	10.1	116.24	118.16	118
BJBf (natural-graded)	0.3	47.50	0.68	1.98	98	4.0	133.88	134.32	134
bulk sp gr = 2.52 (SSD)	0.4	31.28	1.43	3.01	102	8.5	127.88	129.56	128
absorp = 5.61% (OD)	0.5	23.07	2.06	4.07	98	12.3	120.30	122.41	12
FM = 2.72	0.7	17.39	2.74	5.41	98	12.1	116.74	120.12	12
	0.9	13.85	3.46	6.79	101	12.5	114.26	117.36	11
GMRf (natural-graded)	0.3	48.58	0.77	1.93	104	2.3	137.60	138.34	13
bulk sp gr = 2.64 (SSD)	0.4	28.25	1.85	3.32	99	10.1	127.84	128.48	12
absorp = 1.97% (OD)	0.5	22.66	2.53	4.16	98	10.6	124.68	125.87	12
FM = 2.57	0.7	15.79	3.50	5.96	99	14.4	118.06	122.44	12
	0.9	12.34	4.46	7.62	101	14.0	116.85	119.29	12
OO (graded per ASTM C109)	0.3	49.35	0.73	1.91	96	2.1	138.26	138.98	13
bulk sp gr = 2.64 (SSD)	0.4	31.12	1.74	3.02	100	5.2	134.77	137.16	13
absorp = 0.07% (OD)	0.5	23.99	2.44	3.92	100	8.0	131.10	134.28	13
FM = 1.77	0.7	17.59	3.45	5.35	101	7.1	128.09	131.51	13
	0.9	14.23	4.31	6.61	101	6.3	127.13	130.32	12
SS (graded per Calif Hwy	0.3	51.86	0.61	1.81	95	1.3	138.38	139.38	13
Div 1954 std specs)	0.4	32.47	0.78	2.90	99	2.5	138.06	139.84	13
bulk sp gr = 2.63 (SSD)	0.5	24.35	2.43	3.86	101	4.6	134.75	138.13	13
absorp = 1.37% (OD)	0.7	16.96	3.84	5.55	100	5.3	132.15	135.48	13
FM = 2.88	0.9	13.66	4.70	6.88	101	5.8	129.71	133.26	13

Note: (1) All BUD prisms cured and stored in 73.4±2 F air at 100-percent RH.
*Prism compaction: hand-tamped unless noted otherwise.

stic Mortars and Bulk Density of Hardened Mortars Incorporating Sea Water

vg MC, pcf	avg A/C, by wt	avg YIELD, cfsk	avg FLOW, %	avg EAC, %	avg UWP, pcf	*avg BUD, pcf				
						24h	7d	28d	91d	364d
.36	0.50	1.80	99	3.5	133.92	135.40	135.32	135.64	136.56	138.60
.64	1.15	2.72	99	7.3	127.57	128.94	128.11	129.25	129.91	132.94
.74	1.61	3.52	101	10.0	122.03	124.19	124.12	124.58	125.83	129.06
.56	2.30	4.81	104	10.5	118.21	121.70	122.40	122.09	122.88	127.38
.62	2.92	6.02	101	10.1	116.24	118.16	118.97	122.40	120.53	123.38
.50	0.68	1.98	98	4.0	133.88	134.32	134.43	135.48	136.29	137.68
.28	1.43	3.01	102	8.5	127.88	129.56	128.94	128.53	129.98	132.24
.07	2.06	4.07	98	12.3	120.30	122.41	122.67	123.34	124.79	128.98
.39	2.74	5.41	98	12.1	116.74	120.12	120.82	120.74	122.25	126.41
.85	3.46	6.79	101	12.5	114.26	117.36	118.11	118.35	120.12	121.13
.58	0.77	1.93	104	2.3	137.60	138.34	137.45	139.22	139.74	141.00
.25	1.85	3.32	99	10.1	127.84	128.48	129.35	129.97	130.60	133.50
.66	2.53	4.16	98	10.6	124.68	125.87	126.29	126.76	127.54	130.03
.79	3.50	5.96	99	14.4	118.06	122.44	12[illegible]	122.30	123.13	123.57
.34	4.46	7.62	101	14.0	116.85	119.29	121.16	120.84	122.29	125.20
.35	0.73	1.91	96	2.1	138.26	138.98	139.38	140.31	140.00	141.87
.12	1.74	3.02	100	5.2	134.77	137.16	137.54	137.54	138.53	138.90
.99	2.44	3.92	100	8.0	131.10	134.28	134.55	135.32	134.86	136.89
.59	3.45	5.35	101	7.1	128.09	131.51	131.68	132.05	132.80	131.93
.23	4.31	6.61	101	6.3	127.13	130.32	129.89	130.56	131.56	131.93
.86	0.61	1.81	95	1.3	138.38	139.38	139.22	140.31	141.34	141.70
.47	0.78	2.90	99	2.5	138.06	139.84	139.84	140.46	140.68	141.55
.35	2.43	3.86	101	4.6	134.75	138.13	136.42	137.72	138.65	139.85
.96	3.84	5.55	100	5.3	132.15	135.48	135.17	135.01	135.88	138.10
.66	4.70	6.88	101	5.8	129.71	133.26	132.68	133.56	132.95	136.72

in 73.4±2 F air at 100-percent RH.
d otherwise.

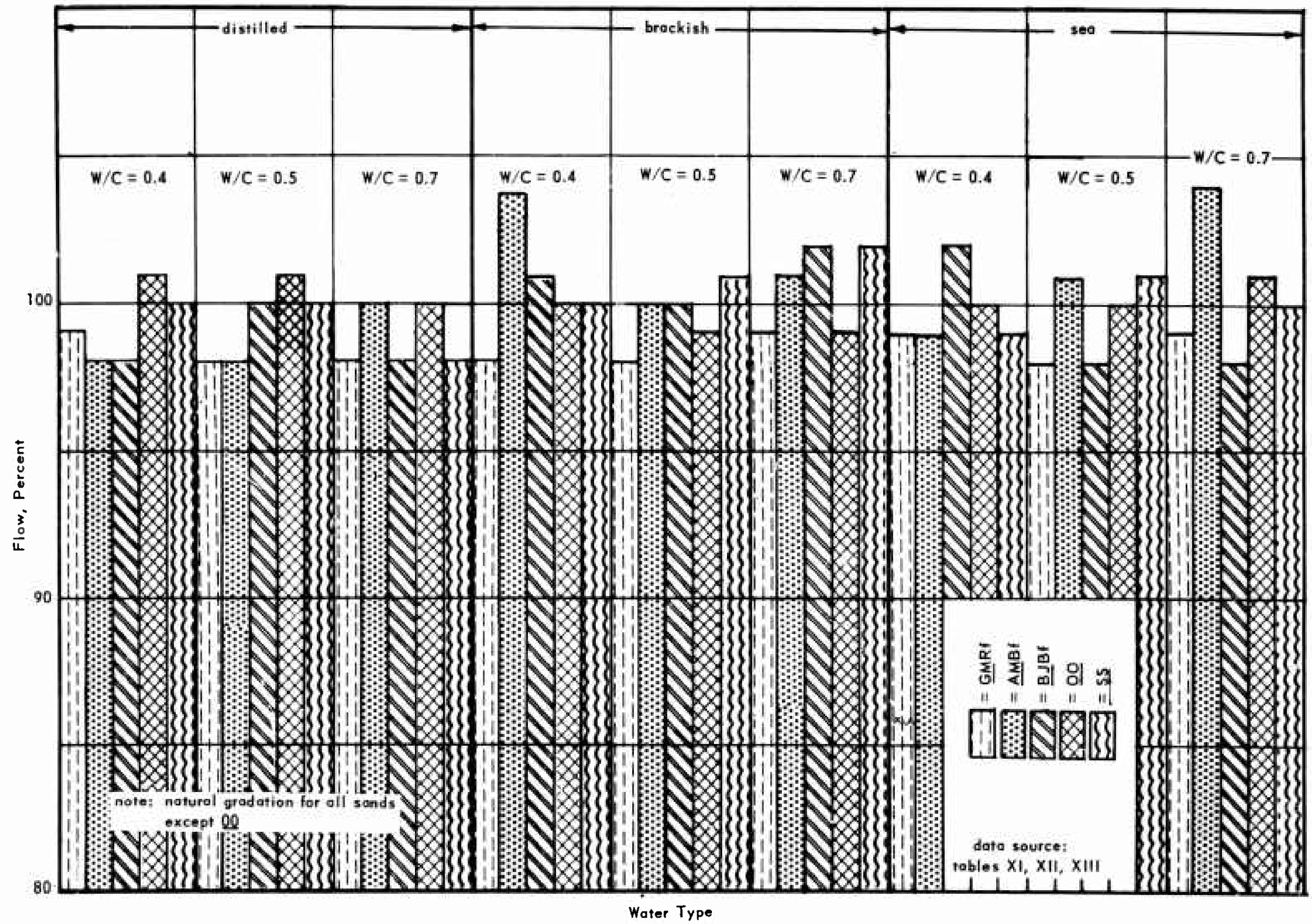


Figure 23. Correlation 2a-a'.

Correlation 2g-a'.

This relationship is represented graphically in Figure 24. Throughout the range of W/C values investigated, it is apparent that the effect of sea water in any mortar mix influences the flow variation to the degree explained in Correlation 2a-a' and apparently obscures any effects due to change in W/C. To maintain a flow of 100 percent for various values of W/C necessitates adjustment of the A/C (aggregate-cement ratio) and CMC (cement content) corresponding to the mix in question; but the type of water overshadows these two factors and thus eliminates Correlations 2f-a' and 2h-a' from further study.

Correlation 2h-a'.

See Section 18 and last sentence above concerning Correlation 2g-a'.

Correlation 2i-a'.

Though the scarcity of data does not permit firm establishment of trends, the relationships delineated in Figure 25 disclose that coral sand mortars may tend to exhibit less flow with increasing EAC. Mortars incorporating R-derived sands probably decrease in flow at a comparatively rapid rate with increase in EAC, regardless of type of mix water. On the other hand, mortars made with B-derived (beach source) and P-derived (bank-run source) sands appear to be more susceptible to the influence of water type used in the mix, although the comparative rates of increasing flow are practically equal. In any event, the curves constituting Figure 25 are contrary to all expectations; why increased EAC should cause less flow is inexplicable in the light of known facts concerning the "lubricating" properties of air bubbles.

Correlation 2a-b'.

This relationship is satisfied graphically by Correlation 2c-b', shown in Figure 26. It is evident that type of water does not influence yield of coral or reference mortars.

Correlation 2b-b'.

Not evaluated for reasons stated in Section 2.

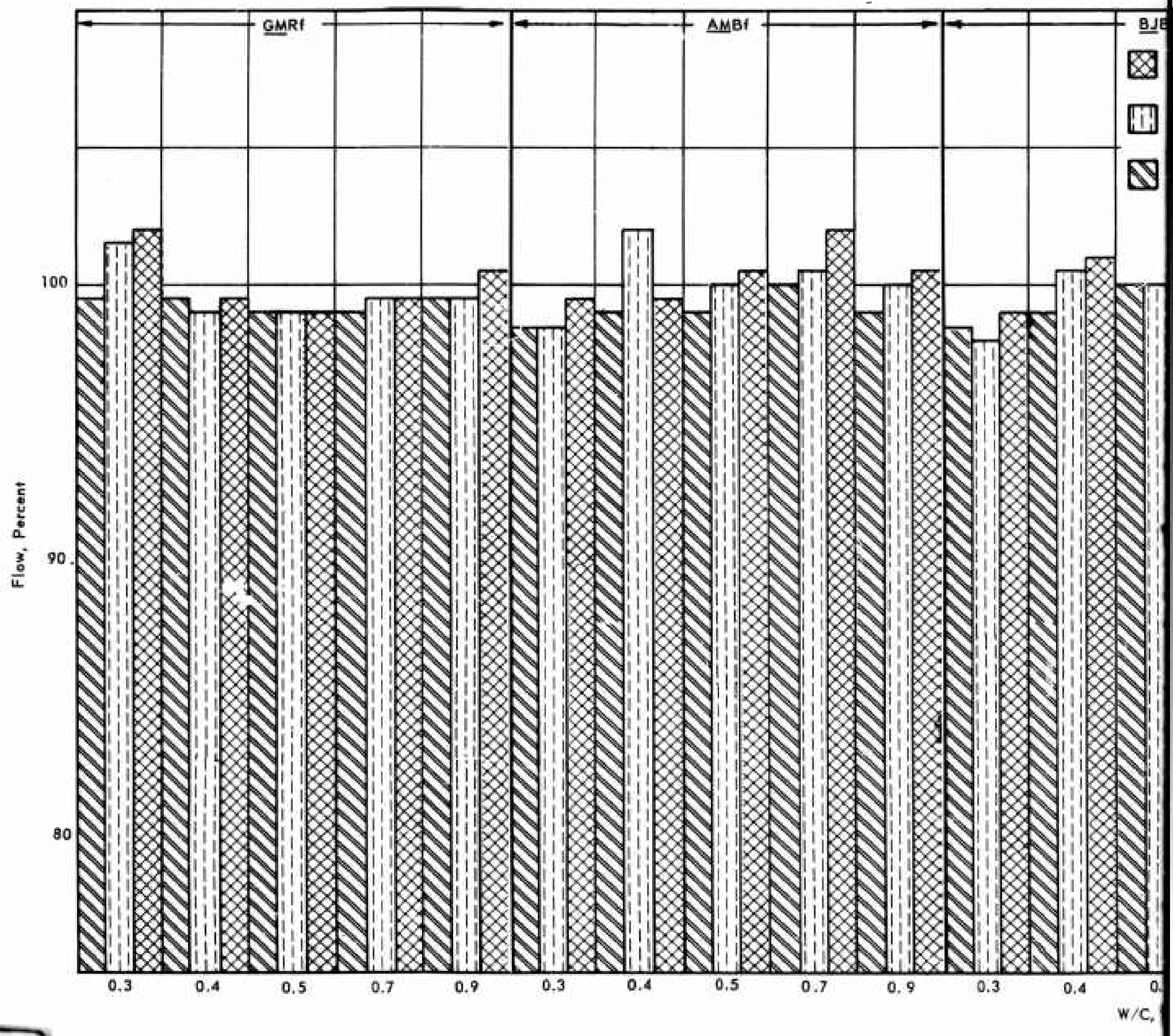
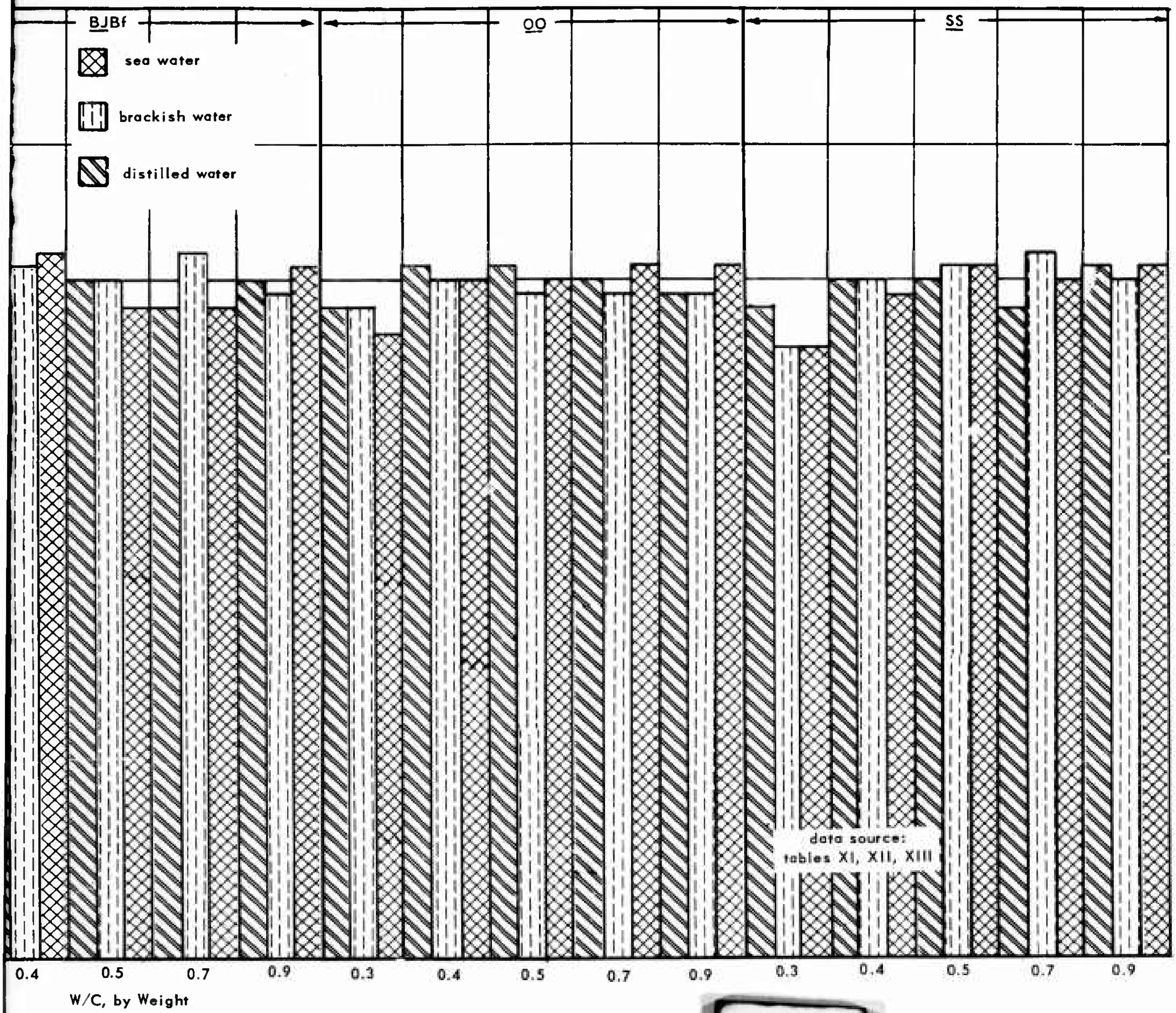


Figure 24. Corr



24. Correlation 2g-a' .

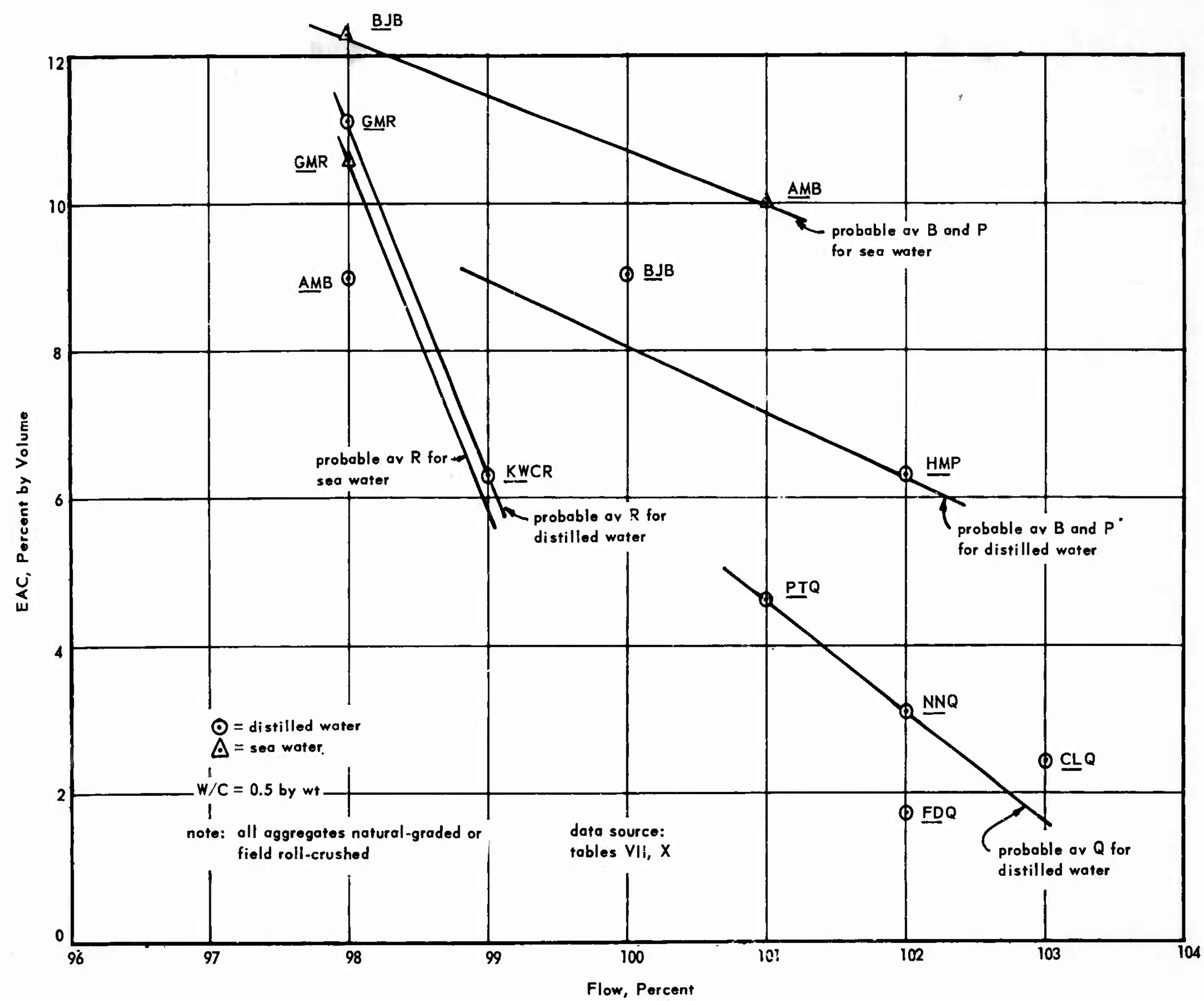


Figure 25. Correlation 2i-a'.

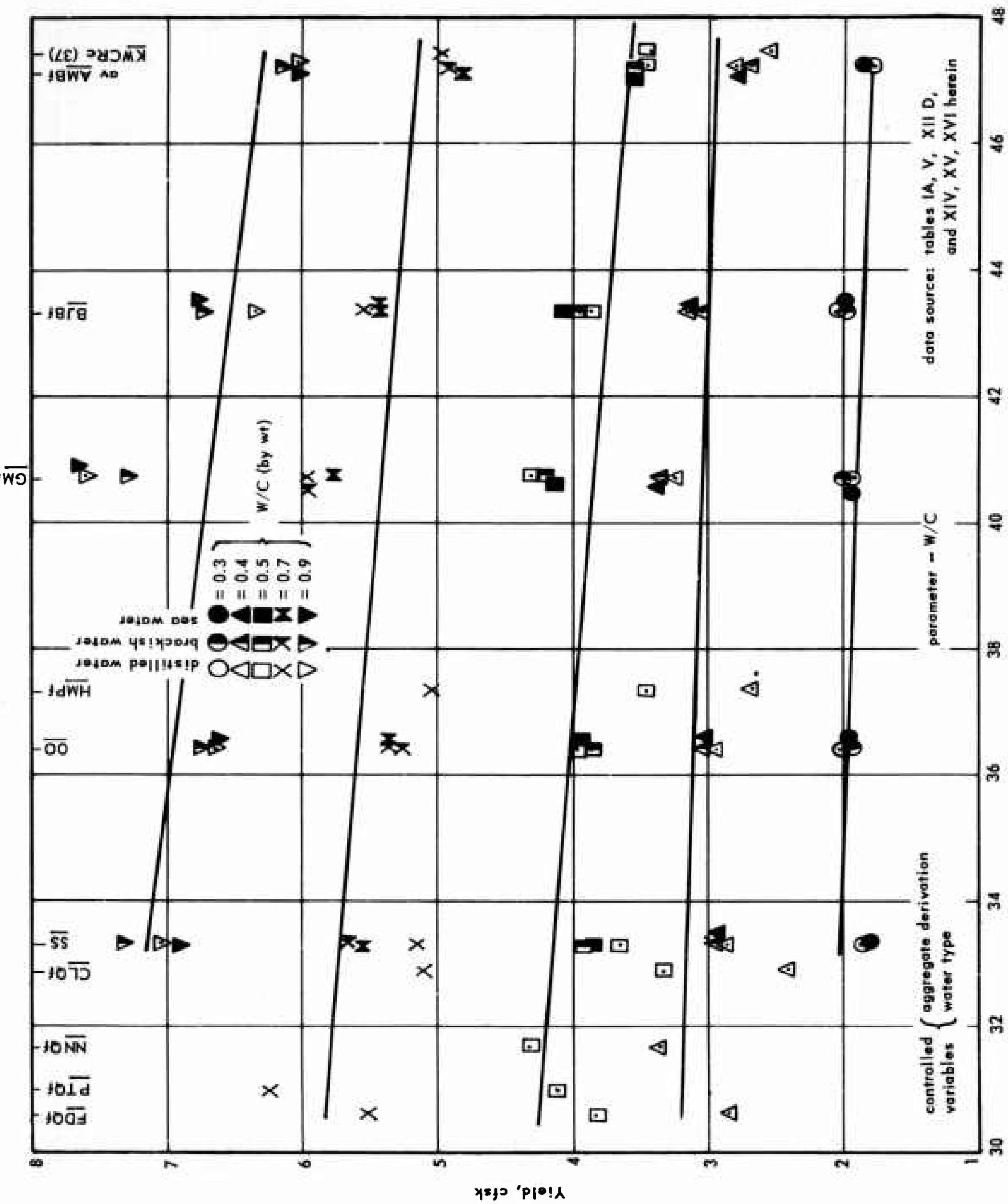


Figure 26. Correlation 2c-b'.

Correlation 2c-b'.

As shown in Figure 26, for W/C values of 0.4 or lower the yield of coral or reference mortars is not affected by percent voids of the sand. For W/C values of 0.5 or greater the data point to a distinct tendency toward increasing yield with decreasing voids. This tendency is most pronounced with mortars (coral as well as reference) having a W/C of 0.9; for such mixes an increase of 15 percent voids would tend to reduce the yield as much as 1 cu ft of mortar per sack of cement.

Correlations 2d-b' and 2e-b'.

Not evaluated for reasons stated in Section 2.

Correlation 2f-b'.

Examination of test data in Tables XIV, XV, and XVI reveals that the variation of yield with CMC change is the same approximately for any mortar included in this investigation. Figures 27, 28, and 29 depict, respectively, the relationship for those mortars involving GMRf, AMBf, and OO. Figure 27 may be considered typical of any mortar involving coral sand, regardless of whether derived from the beach or dredged from the reef, and irrespective of type of water employed in the mix. Stated otherwise, sand derivation and water type exert no appreciable effect upon the relationship between CMC and yield of the mortar under consideration.

Correlation 2g-b'.

Though Figure 30 involves W/C rather than CMC, the loci of the histogram tops for any one coral mortar form a pattern similar to the relationships typified by Figures 27, 28, or 29. It is interesting to note that at low W/C values the yield is nearly equal regardless of sand derivation or water type; at high W/C values the reef-sand mortar, regardless of water type, produces more mortar per sack of cement than mortars fabricated with beach sand, all other things being equal. The explanation may be related principally to particle shape rather than physical condition, surface texture, gradation, specific gravity, and absorption of the sands. Examination of the data in Table XV of Reference 2 shows that both beach sands (AMBf and BJBf) exhibit predominantly subangular characteristics, whereas GMRf is predominantly subround in shape; all three sands are nearly smooth in surface texture; none are radically different in FM, voids, or specific gravity; however, the average percent 24-hour absorption values (Table VIA of Reference 2), computed for oven-dry conditions, are

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Table XIV. Weight Change and Volume Change of Hardened Mortar Prisms Inc

Aggregate Identification	Nominal W/C, by wt	avg CMC, pcf	avg A/C, by wt	avg YIELD, cfsk	avg FLOW, %	avg EAC, %	avg UWP, pcf	*avg	
								24h	7d
AMBf (natural-graded)	0.3	52.42	0.50	1.79	97	3.0	134.06	+0.83	+0.48
bulk sp gr = 2.60 (SSD)	0.4	34.91	1.16	2.69	98	5.9	129.07	+0.53	0.0
absorp = 3.72% (OD)	0.5	27.04	1.62	3.48	98	9.0	123.39	+2.25	+1.98
FM = 2.44	0.7	19.46	2.30	4.83	100	10.3	117.86	+3.31	+4.00
	0.9	15.49	3.05	6.07	98	10.0	116.26	+4.08	+3.95
BJBf (natural-graded)	0.3	46.17	0.75	2.04	97	3.7	134.20	+0.25	+0.72
bulk sp gr = 2.52 (SSD)	0.4	29.57	1.53	3.18	98	8.8	125.81	+2.61	+2.62
absorp = 5.61% (OD)	0.5	24.27	1.99	3.87	100	8.5	124.54	+2.15	+2.23
FM = 2.72	0.7	18.56	2.64	5.43	98	9.0	120.27	+2.97	+3.34
	0.9	14.87	3.29	6.35	100	11.2	116.57	+3.90	+4.32
BJBf (natural-graded)	0.3	35.56	0.68	1.96	97	3.6	134.76	-0.10	+0.30
ditto except vibrated	0.4	30.85	1.51	3.05	98	6.6	129.13	+1.06	+1.24
2 minutes at 0.009-in.	0.5	24.30	1.98	3.87	101	8.4	125.00	+4.35	+3.98
amplitude	0.7	18.23	2.67	5.16	98	9.0	120.81	+5.10	+5.31
	0.9	14.74	3.27	6.38	98	9.4	118.35	+4.61	+3.85
GMRf (natural-graded)	0.3	48.35	0.74	1.94	99	3.1	137.03	-0.01	+0.34
bulk sp gr = 2.64 (SSD)	0.4	29.00	1.81	3.24	99	8.7	129.14	+1.40	+1.52
absorp = 1.97% (OD)	0.5	21.86	2.58	4.30	98	11.1	125.42	+0.41	+1.19
FM = 2.57	0.7	15.78	3.56	5.96	98	13.4	119.20	+1.48	+2.53
	0.9	12.35	4.53	7.61	99	14.5	116.12	+2.19	+3.40
OO (graded per ASTM C109)	0.3	46.52	0.85	2.02	98	1.8	138.02	+1.03	+2.09
bulk sp gr = 2.64 (SSD)	0.4	32.04	1.83	2.94	101	3.7	136.90	+1.31	+1.30
absorp = 0.07% (OD)	0.5	23.55	2.56	3.99	101	4.4	133.36	+2.02	+2.27
FM = 1.77	0.7	17.45	3.54	5.38	100	5.0	130.30	+2.69	+2.90
	0.9	14.11	4.38	6.67	99	4.4	128.38	+2.88	+3.06
SS (graded per Calif Hwy	0.3	51.02	0.65	1.84	98	1.1	138.98	+0.65	+0.84
Div 1954 std specs)	0.4	32.76	1.66	2.87	100	1.3	139.28	+1.16	+0.74
bulk sp gr = 2.63 (SSD)	0.5	25.74	2.30	3.65	102	1.8	137.37	+2.53	+1.91
absorp = 1.37% (OD)	0.7	18.26	3.51	5.15	100	2.2	134.61	+2.47	+2.61
FM = 2.88	0.9	13.32	4.44	7.05	102	2.3	133.21	+2.82	+2.29
SS (ideal-graded)	0.4	32.37	1.67	2.91	101	2.5	137.47	+3.11	+2.09
ditto except vibrated	0.5	24.52	2.44	3.83	98	3.5	136.01	+2.90	+2.49
2 minutes at 0.009-in.	0.7	17.88	3.58	5.26	96	3.6	133.36	+4.77	+3.69
amplitude	0.9	13.68	4.65	6.87	100	5.5	129.05	+7.22	+7.39

Note: (1) WCH measured relative to UWP; increase denoted by (+) sign and decrease denoted by (-)
VCH measured relative to absolute volume of prism during plastic state; swelling denot
(2) All prisms cured and stored in 73.4±2 F air at 100-percent RH.
*Prism compaction: hand-tamped unless noted otherwise.

Volume Change of Hardened Mortar Prisms Incorporating Distilled Water

avg YIELD, cfsk	avg FLOW, %	avg EAC, %	avg UWP, pcf	*avg WCH, %					*avg VCH, %				
				24h	7d	28d	91d	364d	24h	7d	28d	91d	364d
1.79	97	3.0	134.06	+0.83	+0.48	+1.52	+1.60	+2.58	-0.7	+0.1	-0.6	-0.2	-0.8
2.69	98	5.9	129.07	+0.53	0.0	+0.67	+0.80	+2.08	-0.9	-0.5	-0.6	-0.1	-1.2
3.48	98	9.0	123.39	+2.25	+1.98	+2.28	+2.36	+3.76	-1.1	-0.4	-0.5	-0.3	-0.4
4.83	100	10.3	117.86	+3.31	+4.00	+3.69	+3.69	+4.97	-2.1	-2.0	-1.9	-1.6	-1.8
6.07	98	10.0	116.26	+4.08	+3.95	+4.05	+4.14	+4.92	-3.0	-2.2	-1.4	-2.0	-2.4
2.04	97	3.7	134.20	+0.25	+0.72	+0.95	+1.30	+2.12	-0.7	0.0	+0.8	+0.4	+0.2
3.18	98	8.8	125.81	+2.61	+2.62	+2.12	+2.71	+3.87	-0.7	-0.5	+0.2	-0.3	-0.5
3.87	100	8.5	124.54	+2.15	+2.23	+1.73	+2.53	+4.48	-1.3	-0.4	-0.4	0.0	-0.2
5.43	98	9.0	120.27	+2.97	+3.34	+4.03	+3.76	+3.95	-1.3	-1.0	-0.8	-0.9	-0.8
6.35	100	11.2	116. 7	+3.90	+4.32	+4.95	+4.84	+5.97	-1.6	-1.4	-2.3	-1.7	-2.5
1.96	97	3.6	134.76	-0.10	+0.30	+0.99	+1.76	+2.09	0.0	+0.4	+0.2	-0.4	+0.4
3.05	98	6.6	129.13	+1.06	+1.24	+1.90	+1.78	+2.56	-1.6	-1.0	-0.7	-0.5	-0.5
3.87	101	8.4	125.00	+4.35	+3.98	+5.65	+5.14	+4.44	-1.8	-1.0	-0.7	+0.4	-0.9
5.16	98	9.0	120.81	+5.10	+5.31	+5.83	+6.08	+6.00	-1.6	-1.1	-0.2	-0.6	+0.3
6.38	98	9.4	118.35	+4.61	+3.85	+5.09	+6.14	+6.64	-0.5	0.0	-0.7	+1.6	-0.2
1.94	99	3.1	137.03	-0.01	+0.34	+0.90	+1.68	+2.31	-1.0	-0.1	+0.1	+0.4	0.0
3.24	99	8.7	129.14	+1.40	+1.52	+1.35	+1.55	+2.88	-1.0	0.0	-0.6	+0.6	-0.8
4.30	98	11.1	125.42	+0.41	+1.19	+1.18	+1.69	+1.98	+0.3	+0.5	+0.7	+0.9	+1.0
5.96	98	13.4	119.20	+1.48	+2.53	+2.75	+2.63	+3.10	0.0	-0.2	+0.4	+0.1	+0.6
7.61	99	14.5	116.12	+2.19	+3.40	+2.56	+3.44	+3.96	+0.4	+0.7	-1.6	-0.3	-0.5
2.02	98	1.8	138.02	+1.03	+2.09	+2.00	+2.17	+2.97	-0.7	-0.2	-0.3	+0.6	+0.1
2.94	101	3.7	136.90	+1.31	+1.30	+2.65	+2.42	+2.48	-1.1	+0.3	-1.0	-0.1	0.0
3.99	101	4.4	133.36	+2.02	+2.27	+2.20	+2.29	+3.41	+0.1	+0.5	+0.4	+1.4	-0.3
5.38	100	5.0	130.30	+2.69	+2.90	+3.26	+3.17	+3.69	-1.3	-1.1	-1.5	-0.7	-1.3
6.67	99	4.4	128.38	+2.88	+3.06	+3.44	+3.26	+3.73	-1.8	-1.8	-1.7	-1.5	-1.1
1.84	98	1.1	138.98	+0.65	+0.84	+1.63	+1.63	+2.39	-0.2	-0.1	-0.3	+0.4	+0.2
2.87	100	1.3	139.28	+1.16	+0.74	+1.55	+1.92	+2.17	+0.1	+0.8	+1.2	+0.9	+0.9
3.65	102	1.8	137.37	+2.53	+1.91	+2.26	+2.28	+2.93	-1.2	+1.5	+0.5	+0.9	+0.3
5.15	100	2.2	134.61	+2.47	+2.61	+2.84	+3.37	+3.56	-1.1	-0.8	-0.8	-1.0	-1.2
7.05	102	2.3	133.21	+2.82	+2.29	+2.42	+2.84	+3.22	-2.0	-1.2	-0.8	-1.0	-1.2
2.91	101	2.5	137.47	+3.11	+2.09	+2.26	+3.02	+3.76	-0.7	+0.2	+0.1	0.0	-0.1
3.83	98	3.5	136.01	+2.90	+2.49	+2.50	+3.54	+4.32	-1.2	-0.6	-0.5	-0.9	-0.2
5.26	96	3.6	133.36	+4.77	+3.69	+4.51	+4.93	+6.14	-1.5	-0.9	-0.9	-1.0	-1.2
6.87	100	5.5	129.05	+7.22	+7.39	+7.00	+7.77	+7.63	-1.4	-1.4	-1.1	-1.1	-1.3

ted by (+) sign and decrease denoted by (-) sign.
prism during plastic state; swelling denoted by (+) sign and shrinkage denoted by (-) sign.
at 100-percent RH.
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Table XV. Weight Change and Volume Change of Hardened Mortar Pr

Aggregate Identification	Nominal W/C, by wt	avg CMC, pcf	avg A/C, by wt	avg YIELD, cfsk	avg FLOW, %	avg EAC, %	avg UWP, pcf		
								24h	
AMBf (natural-graded)	0.3	52.05	0.53	1.81	97	3.0	134.22	+0.41**	+1
bulk sp gr = 2.60 (SSD)	0.4	34.76	1.15	2.70	104	6.6	128.04	+1.53	+1
absorp = 3.72% (OD)	0.5	26.83	1.61	3.51	100	9.4	122.38	+2.11	+1
FM = 2.44	0.7	19.26	2.34	4.88	101	11.2	117.23	+3.70	+3
	0.9	15.39	2.93	6.11	100	10.9	114.71	+3.15	+2
BJBf (natural-graded)	0.3	47.96	0.66	1.96	96	3.8	133.97	+0.52	+0
bulk sp gr = 2.52 (SSD)	0.4	30.78	1.44	3.05	101	7.9	127.26	+2.04	+1
absorp = 5.61% (OD)	0.5	23.78	2.04	3.95	100	9.8	123.25	+1.20	+1
FM = 2.72	0.7	17.39	2.74	5.41	102	11.9	116.76	+3.33	+4
	0.9	13.96	3.41	6.74	99	12.0	114.43	+3.84	+4
GMRf (natural-graded)	0.3	48.35	0.72	1.94	103	2.8	136.61	-0.56	+
bulk sp gr = 2.64 (SSD)	0.4	28.43	1.85	3.30	98	9.4	128.58	+2.15	+
absorp = 1.97% (OD)	0.5	22.15	2.46	4.24	98	11.7	124.10	+1.53	+
FM = 2.57	0.7	16.26	3.38	5.78	99	12.9	119.74	+2.35	+
	0.9	12.89	4.34	7.30	99	12.8	117.85	+1.24	+
OO (graded per ASTM C109)	0.3	48.98	0.77	1.92	98	1.9	138.34	+0.54	+
bulk sp gr = 2.64 (SSD)	0.4	31.36	1.73	3.00	100	4.5	135.23	+2.13	+
absorp = 0.07% (OD)	0.5	24.34	2.42	3.86	99	5.5	132.60	+1.86	+
FM = 1.77	0.7	17.87	3.47	5.27	99	6.9	129.28	+2.21	+
	0.9	14.10	4.37	6.67	99	6.3	126.93	+2.89	+
SS (graded per Calif Hwy	0.4	32.44	1.66	2.90	100	2.3	137.94	+1.69	+
Div 1954 std specs)	0.5	24.08	2.52	3.90	101	5.1	133.71	+2.61	+
bulk sp gr = 2.63 (SSD)	0.7	16.63	3.81	5.65	102	6.9	129.75	+4.00	+
absorp = 1.37% (OD)	0.9	12.83	4.22	7.33	100	7.9	127.35	+3.38	+
FM = 2.88									

Note: (1) WCH measured relative to UWP; increase denoted by (+) sign and decrease denoted by (
VCH measured relative to absolute volume of prism during plastic state; swelling den
(2) All prisms cured and stored in 73.4±2 F air at 100-percent RH.

*Prism compaction: hand-tamped unless noted otherwise.
**Vibrated 2 minutes at 0.009-in. amplitude.

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ge of Hardened Mortar Prisms Incorporating Brackish Water

g C,	avg UWP, pcf	*avg WCH, %					*avg VCH, %				
		24h	7d	28d	91d	364d	24h	7d	28d	91d	364d
0	134.22	+0.41**	+1.28**	+1.40**	+0.39**	+2.81**	+0.6**	+0.8**	+0.7**	+0.5**	+0.1**
6	128.04	+1.53	+1.68	+1.82	+2.65	+4.10	-0.7	-0.3	+1.2	-0.5	0.0
4	122.38	+2.11	+1.92	+1.67	+2.44	+4.10	-1.2	-0.5	0.0	-0.2	-0.9
2	117.23	+3.70	+3.74	+4.01	+3.90	+5.07	-1.7	-0.8	+0.4	-0.7	-0.9
9	114.71	+3.15	+2.49	+3.99	+3.71	+5.60	-2.6	-2.4	-2.3	-2.0	-1.7
.8	133.97	+0.52	+0.71	+1.46	+1.73	+2.37	-0.3	-0.3	-0.5	+0.4	-0.3
9	127.26	+2.04	+1.97	+1.81	+2.53	+2.94	-0.7	+0.4	+0.4	+0.1	+0.3
.8	123.25	+1.20	+1.58	+2.09	+1.92	+2.96	-0.9	-0.6	-0.8	-0.1	-0.5
.9	116.76	+3.33	+4.29	+4.56	+3.90	+5.07	-1.1	-1.6	-1.6	-1.1	-2.0
.0	114.43	+3.84	+4.38	+4.26	+5.20	+6.89	-2.7	-2.4	-2.1	-2.4	-3.2
.8	136.61	-0.56	+0.37	+0.82	+1.73	+1.71	+0.6	+0.5	+0.8	+0.7	+0.2
.4	128.58	+2.15	+2.03	+2.03	+2.74	+3.48	-0.8	-0.2	+0.2	-1.0	-0.5
.7	124.10	+1.53	+2.47	+1.77	+2.65	+3.64	-0.1	+0.2	+0.7	+1.2	+0.2
.9	119.74	+2.35	+2.48	+2.78	+2.89	+4.05	-1.7	-1.5	-1.7	-0.8	-1.7
.8	117.85	+1.24	+2.37	+1.83	+2.89	+3.50	-1.2	-2.4	-1.5	-1.2	-2.0
.9	138.34	+0.54	+1.39	+1.58	+1.85	+2.38	-0.2	-0.3	+0.2	-0.4	+0.4
.5	135.23	+2.13	+2.07	+2.44	+3.18	+3.28	-0.5	0.0	0.0	+0.1	+0.3
.5	132.60	+1.86	+2.13	+2.65	+2.97	+3.24	-0.4	0.0	+0.5	-0.2	-0.3
.9	129.28	+2.21	+2.51	+2.75	+3.07	+2.74	-1.4	-1.4	-1.2	-0.4	-0.7
.3	126.93	+2.89	+3.06	+3.25	+3.15	+3.84	-1.7	-1.4	-1.2	-1.4	-1.2
.3	137.94	+1.69	+1.49	+1.55	+2.12	+3.18	-0.4	+0.2	+0.6	+0.4	+0.3
.1	133.71	+2.61	+2.14	+2.27	+2.62	+3.66	-1.0	-0.3	-0.2	+0.3	+0.1
.9	129.75	+4.00	+2.62	+3.06	+3.59	+3.95	-1.9	-0.5	0.0	-0.9	-1.0
.9	127.35	+3.38	+3.08	+3.26	+3.53	+4.79	-1.2	-0.6	-0.8	-1.0	-1.1

d decrease denoted by (-) sign.
tic state; swelling denoted by (+) sign and shrinkage denoted by (-) sign.
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Table XVI. Weight Change and Volume Change of Hardened Mortar

Aggregate Identification	Nominal W/C, by wt	avg CMC, pcf	avg A/C, by wt	avg YIELD, cfsk	avg FLOW, %	avg EAC, %	avg UWP, pcf	
								24h
AMBf (natural-graded)	0.3	52.36	0.50	1.80	99	3.5	133.92	+1.11
bulk sp gr = 2.60 (SSD)	0.4	34.64	1.15	2.72	99	7.3	127.57	+1.07
absorp = 3.72% (OD)	0.5	26.74	1.61	3.52	101	10.0	122.03	+1.77
FM = 2.44	0.7	19.56	2.30	4.81	104	10.5	118.21	+2.94
	0.9	15.62	2.92	6.02	101	10.1	116.24	+1.65
BJBf (natural-graded)	0.3	47.50	0.68	1.98	98	4.0	133.88	+0.33
bulk sp gr = 2.52 (SSD)	0.4	31.28	1.43	3.01	102	8.5	127.88	+1.31
absorp = 5.61% (OD)	0.5	23.07	2.06	4.07	98	12.3	120.30	+1.75
FM = 2.72	0.7	17.39	2.74	5.41	98	12.1	116.74	+2.90
	0.9	13.85	3.46	6.79	101	12.5	114.26	+2.71
GMRf (natural-graded)	0.3	48.58	0.77	1.93	104	2.3	137.60	+0.54
bulk sp gr = 2.64 (SSD)	0.4	28.25	1.85	3.32	99	10.1	127.84	+0.50
absorp = 1.97% (OD)	0.5	22.66	2.53	4.16	98	10.6	124.68	+1.04
FM = 2.57	0.7	15.79	3.50	5.96	99	14.4	118.06	+3.66
	0.9	12.34	4.46	7.62	101	14.0	116.85	+1.22
OO (graded per ASTM C109)	0.3	49.35	0.73	1.91	96	2.1	138.26	+0.53
bulk sp gr = 2.64 (SSD)	0.4	31.12	1.74	3.02	100	5.2	134.77	+1.77
absorp = 0.07% (OD)	0.5	23.99	2.44	3.92	100	8.0	131.10	+2.43
FM = 1.77	0.7	17.59	3.45	5.35	101	7.1	128.09	+2.67
	0.9	14.23	4.31	6.61	101	6.3	127.13	+2.51
SS (graded per 1954 Calif	0.3	51.86	0.61	1.81	95	1.3	138.38	+0.72
Hwy Div Std specs)	0.4	32.47	0.78	2.90	99	2.5	138.06	+1.29
bulk sp gr = 2.63 (SSD)	0.5	24.35	2.43	3.86	101	4.6	134.75	+2.51
absorp = 1.37% (OD)	0.7	16.96	3.84	5.55	100	5.3	132.15	+2.52
FM = 2.88	0.9	13.66	4.70	6.88	101	5.8	129.71	+3.14

Note: (1) WCH measured relative to UWP; increase denoted by (+) sign and decrease denoted by (
VCH measured relative to absolute volume of prism during plastic state; swelling den

*Prism compaction: hand-tamped.

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me Change of Hardened Mortar Prisms Incorporating Sea Water.

avg EAC, %	avg UWP, pcf	*avg WCH, %					*avg VCH, %				
		24h	7d	28d	91d	364d	24h	7d	28d	91d	364d
3.5	133.92	+1.11	+0.93	+1.28	+1.97	+3.49	-0.2	+0.1	+0.4	+0.6	-0.2
7.3	127.57	+1.07	+0.49	+1.32	+1.83	+4.20	-1.0	-1.5	+0.2	+0.8	-0.2
10.0	122.03	+1.77	+1.71	+2.09	+3.10	+5.76	0.0	+0.8	+1.3	+0.6	-0.4
10.5	118.21	+2.94	+3.54	+3.28	+3.94	+7.75	-0.9	-0.8	-0.2	+0.5	-0.8
10.1	116.24	+1.65	+2.36	+5.17	+3.69	+6.14	-2.2	-1.8	-2.8	-1.6	-2.2
4.0	133.88	+0.33	+0.41	+1.20	+1.80	+2.84	-0.2	+0.1	+0.3	+0.9	+0.4
8.5	127.88	+1.31	+0.88	+0.50	+1.64	+3.41	+0.8	+1.4	+2.3	+0.8	+1.2
12.3	120.30	+1.75	+1.97	+2.53	+3.73	+7.22	-0.4	-0.2	+0.1	-0.1	-0.6
12.1	116.74	+2.90	+3.50	+3.43	+4.72	+8.28	-2.1	-1.8	-1.4	-1.5	-2.1
12.5	114.26	+2.71	+3.37	+3.58	+5.13	+6.00	-2.7	-2.6	-2.0	-2.8	+0.9
2.3	137.60	+0.54	-0.10	+1.29	+1.56	+2.47	+2.7	+1.7	+1.4	+1.8	+1.1
10.1	127.84	+0.50	+1.18	+1.67	+2.16	+4.43	-0.4	+0.2	+0.1	+0.9	-0.4
10.6	124.68	+1.04	+1.41	+2.08	+2.58	+4.40	+1.9	+2.3	+2.5	+0.9	+0.2
14.4	118.06	+3.66	+4.24	+3.54	+4.24	+4.96	-0.6	-1.3	-0.6	-0.7	-1.3
14.0	116.85	+1.22	+0.56	+4.16	+4.48	+6.07	-1.5	-1.3	-1.9	-1.0	-1.0
2.1	138.26	+0.53	+0.81	+1.48	+1.26	+2.61	+0.3	+0.6	+0.7	+0.7	+0.6
5.2	134.77	+1.77	+2.06	+2.06	+2.79	+3.07	-0.4	+0.3	+0.9	+0.8	+0.6
8.0	131.10	+2.43	+2.62	+3.22	+2.86	+4.41	+0.2	+0.4	+0.9	+0.8	+0.9
7.1	128.09	+2.67	+2.80	+3.09	+3.68	+4.45	0.0	0.0	-0.5	-0.4	-0.2
6.3	127.13	+2.51	+2.17	+2.69	+3.48	+3.97	-0.7	-0.2	-0.9	-0.1	-0.8
1.3	138.38	+0.72	+0.61	+1.39	+2.15	+2.40	-0.4	+0.5	+0.2	+0.2	+0.6
2.5	138.06	+1.29	+1.29	+1.74	+1.90	+2.53	+0.2	+0.8	+1.0	+1.3	+0.7
4.6	134.75	+2.51	+1.60	+2.46	+2.89	+3.78	-1.0	-0.2	+0.1	-0.3	0.0
5.3	132.15	+2.52	+2.28	+2.16	+2.83	+4.50	-1.3	-0.4	-1.0	-0.8	-0.1
5.8	129.71	+3.14	+2.69	+3.37	+2.31	+5.23	-0.9	-0.2	-0.8	-0.3	-1.0

n and decrease denoted by (-) sign.
plastic state; swelling denoted by (+) sign and shrinkage denoted by (-) sign.

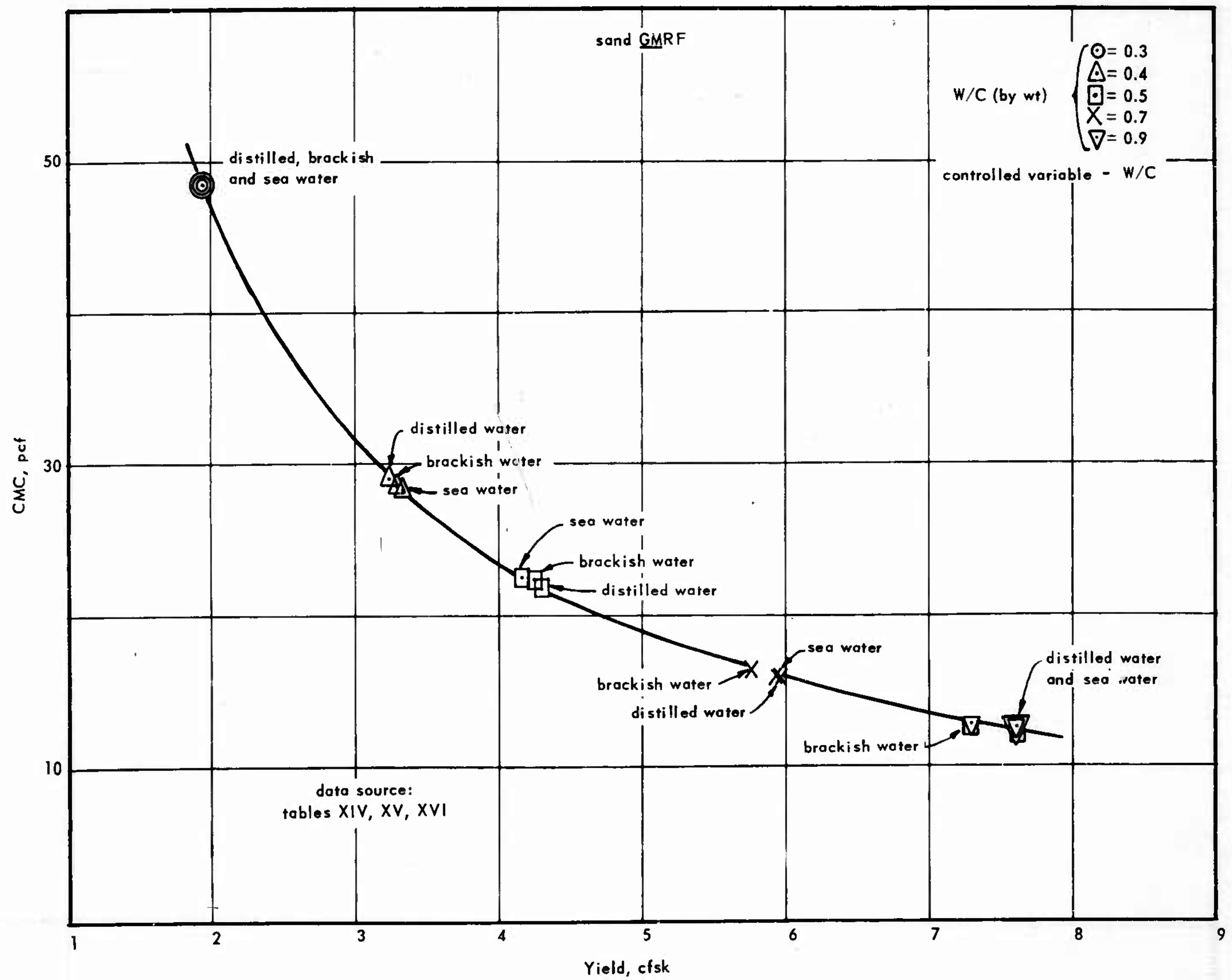

Figure 27. Correlation 2f-b'.

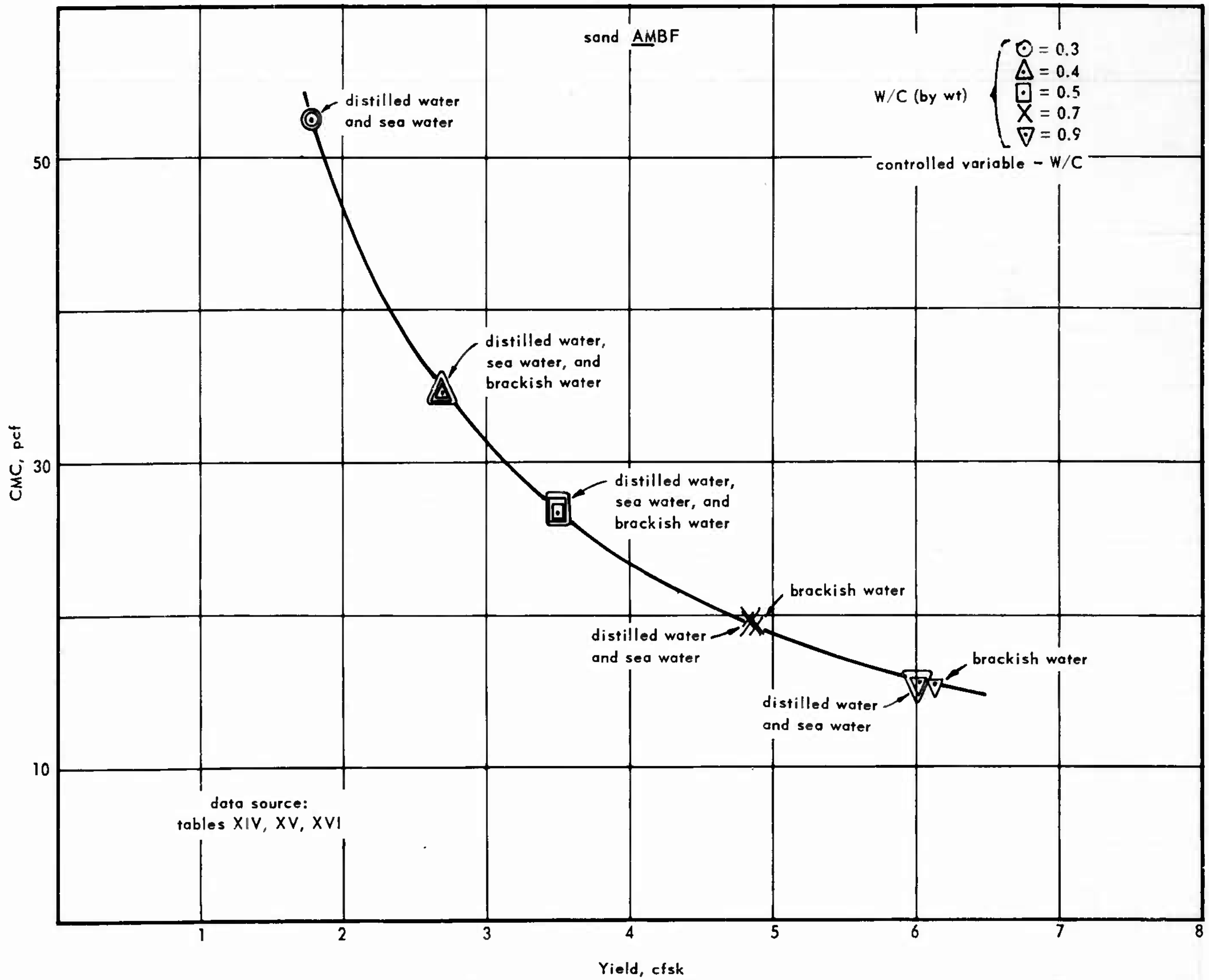

Figure 28. Correlation 2f-b'.

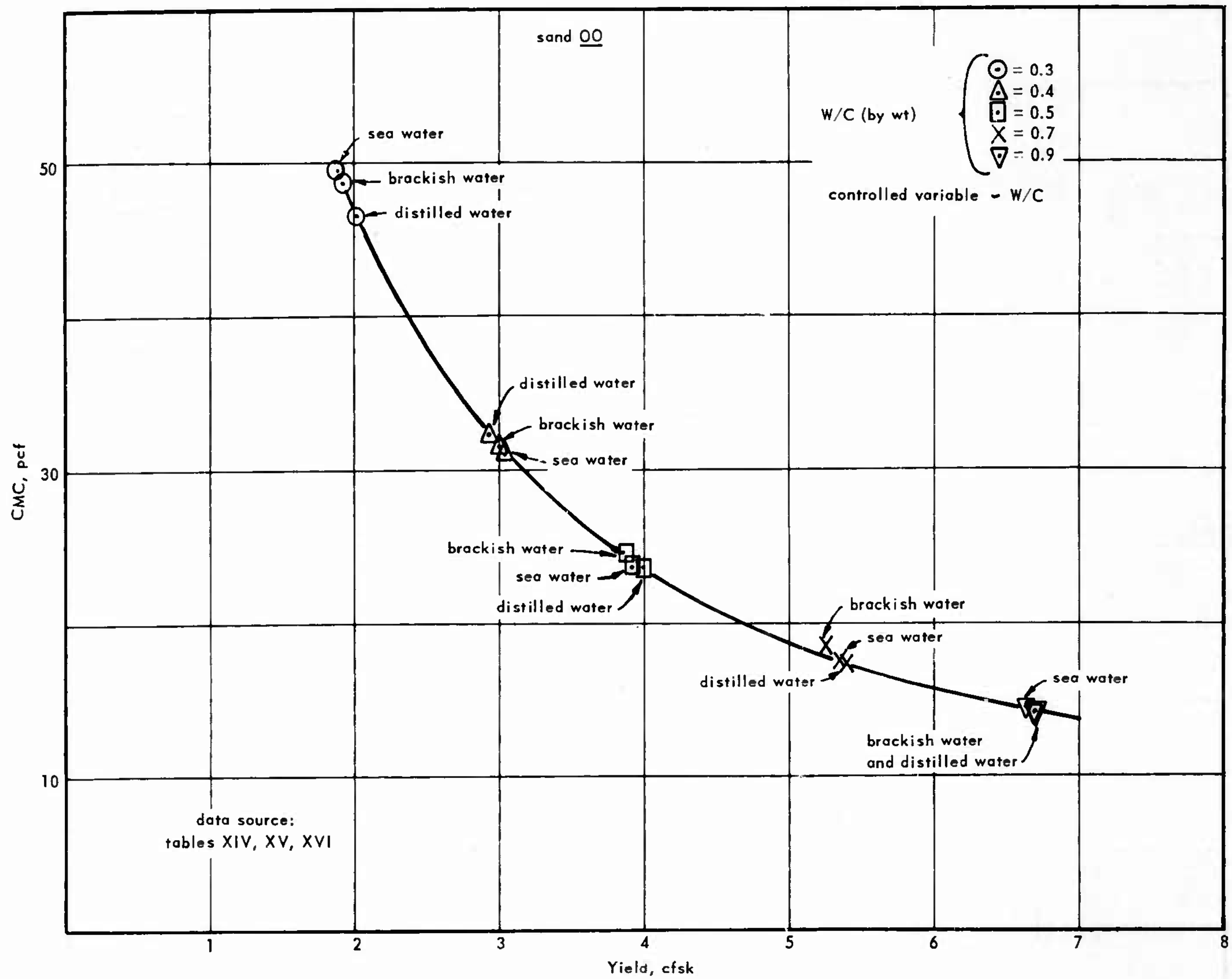

Figure 29. Correlation 2f-b'.

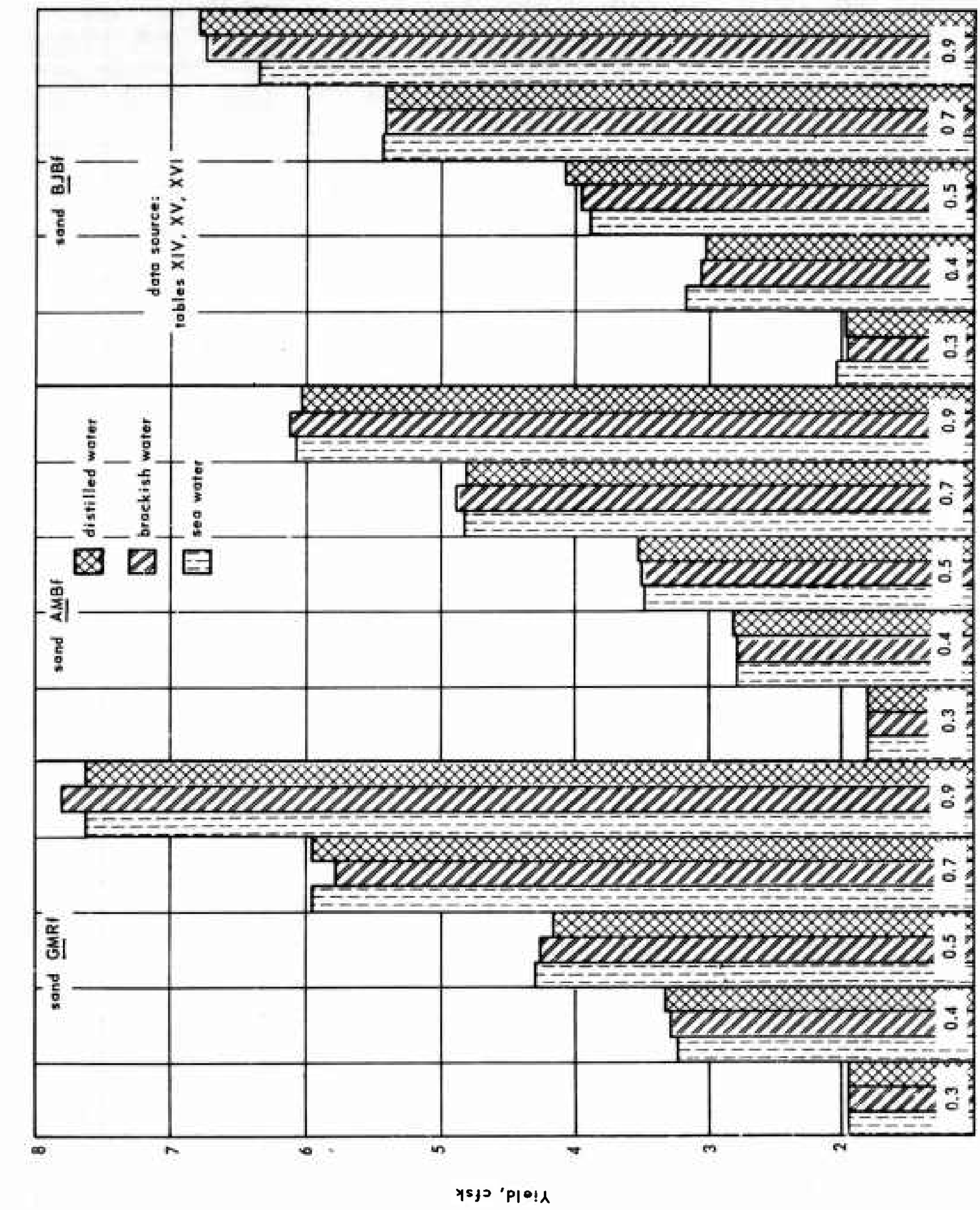

Figure 30. Correlation 2g-b'.

rather different (3.72 for AMBf, 5.61 for BJBf, and 1.97 for GMRf). Figure 30 could serve very well as the source of two curves, one for beach and one for reef coral sand mortars; these two curves would be typical of the mortar yields to be expected for various W/C values, regardless of type of water employed in the mixes.

Correlation 2h-b'.

Figure 31 demonstrates that the effect of A/C upon mortar yield is not influenced by type of water incorporated in the mix. The graph could involve either a straight line or the slight curve shown and the amount of mortar yield always would be about twice the numerical value of the A/C; this deduction, of course, would be valid only for mortars possessing flow values (and related characteristics) similar to those used in this investigation.

Correlation 2i-b'.

The extent to which EAC affects yield is illustrated in Figures 32 to 36, inclusive. Mortars that incorporate reference sands need only about one-half the EAC of mortars fabricated with coral beach sands, and only about one-third the EAC of mortars incorporating coral reef sands, to attain maximun yield; this observation is true regardless of type of water employed. Study of the illustrations leads to the belief that the maximum yield possible with coral reef-sand mortars may be considerably higher, with increasing EAC, than attainable with coral beach-sand mortars. For the coral mortar mixes used in this investigation, the maximum EAC is a criterion of maximum yield only if the mortar contains coral reef sand.

Correlation 3a-a'.

As shown in Figures 37, 38, and 39, the degree of compaction employed in computing UNW (unit weight or bulk density) of sand is of no practical importance relative to the average variation of EAC of mortar with changing UNW values. The type of water used in mortars exerts no noteworthy effect upon the relationship between mortar EAC and sand UNW; for the W/C values shown, the estimated slopes of the curves are quite similar regardless of type of water in the mixes. Of greater significance is the following: (1) at extremely low W/C values coral beach-sand mortars exhibit about twice as much EAC as do mortars made with coral reef-sands and (2) when the W/C is 0.9 the EAC of coral beach-sand mortars is slightly less than that of coral reef-sand mortars. These latter observations are valid, irrespective of whether brackish or sea waters are employed, provided that all other mix-design factors are approximately equal.

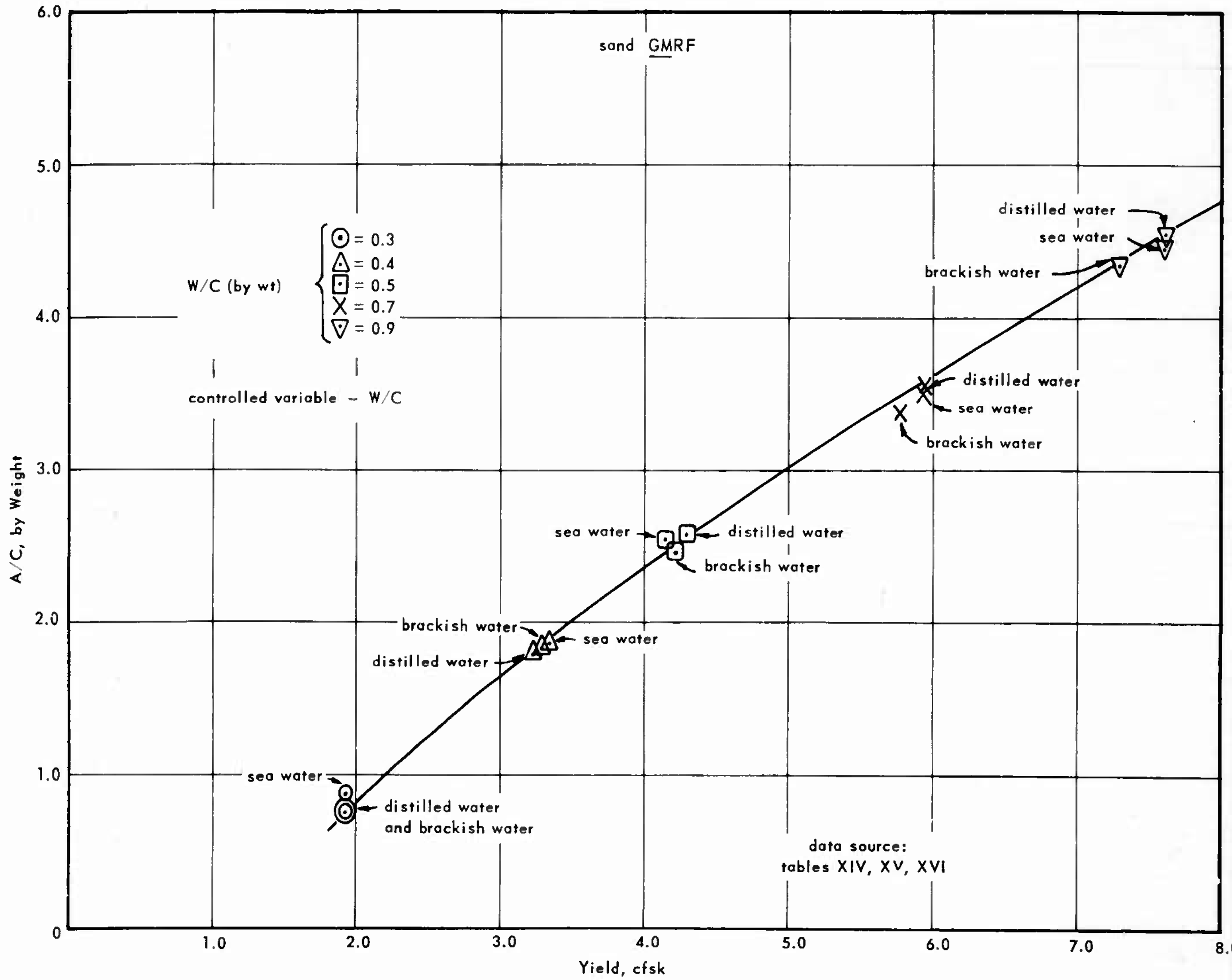

Figure 31. Correlation 2h-b'.

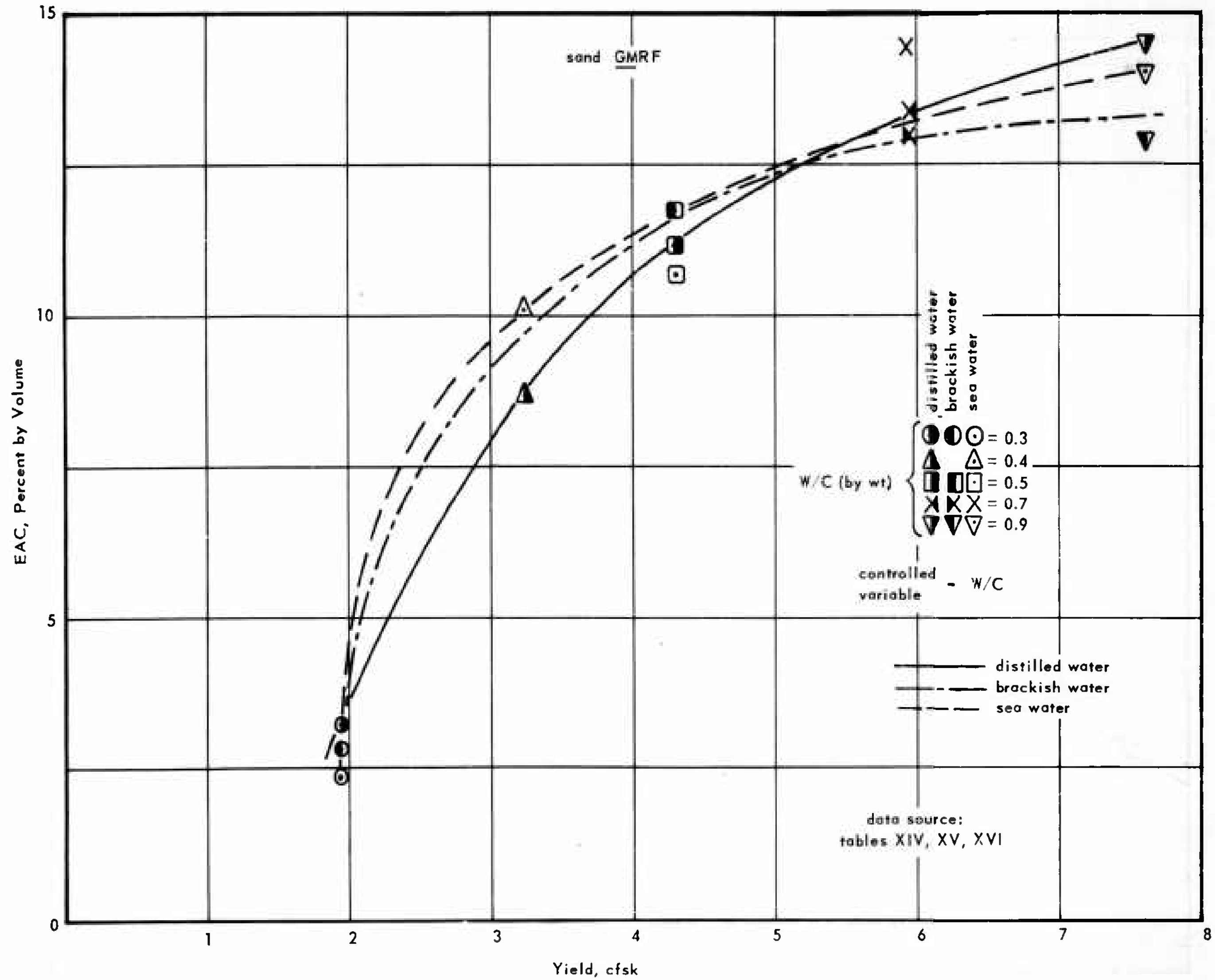

Figure 32. Correlation 2i-b'.

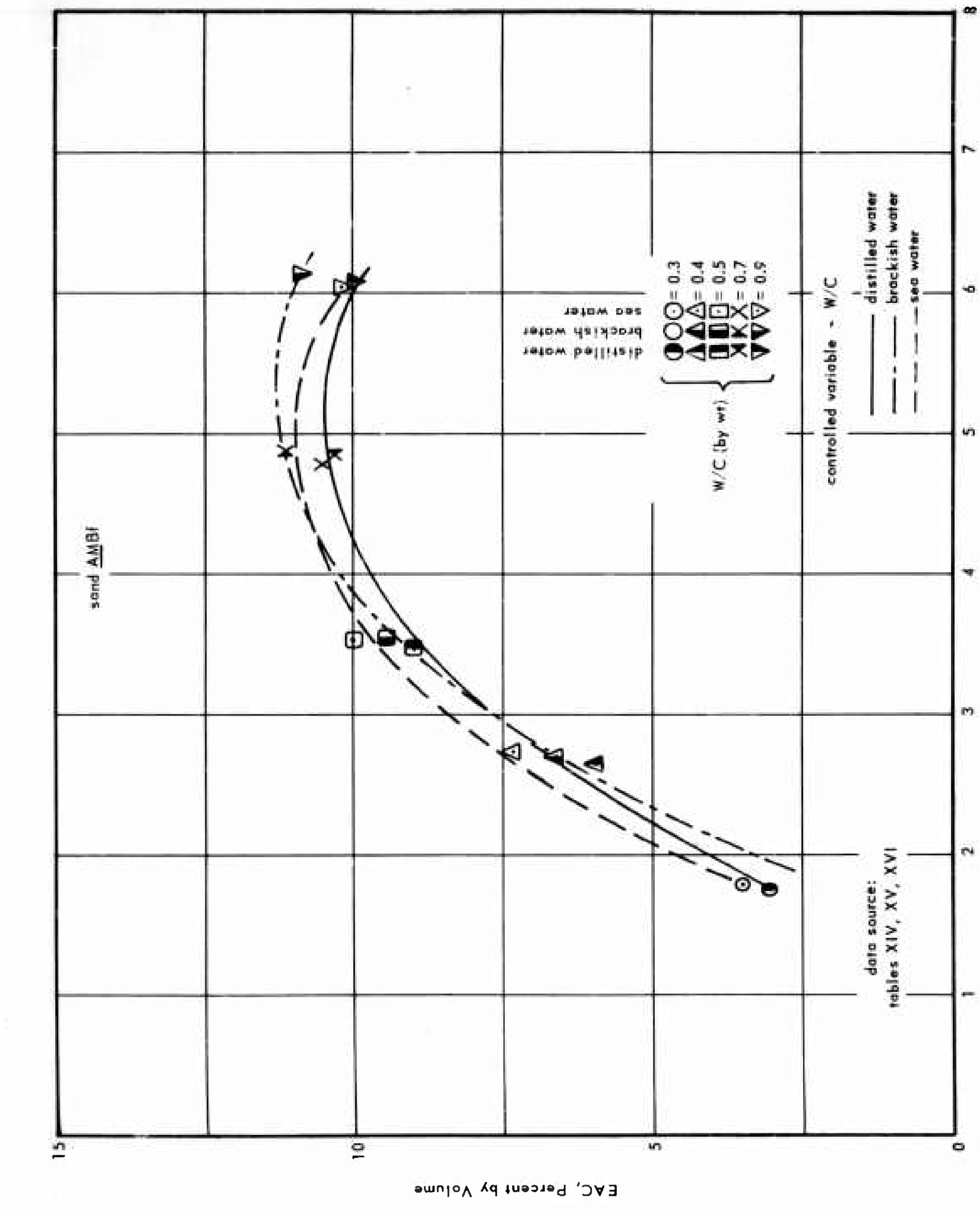

Figure 33. Correlation 2i-b'.

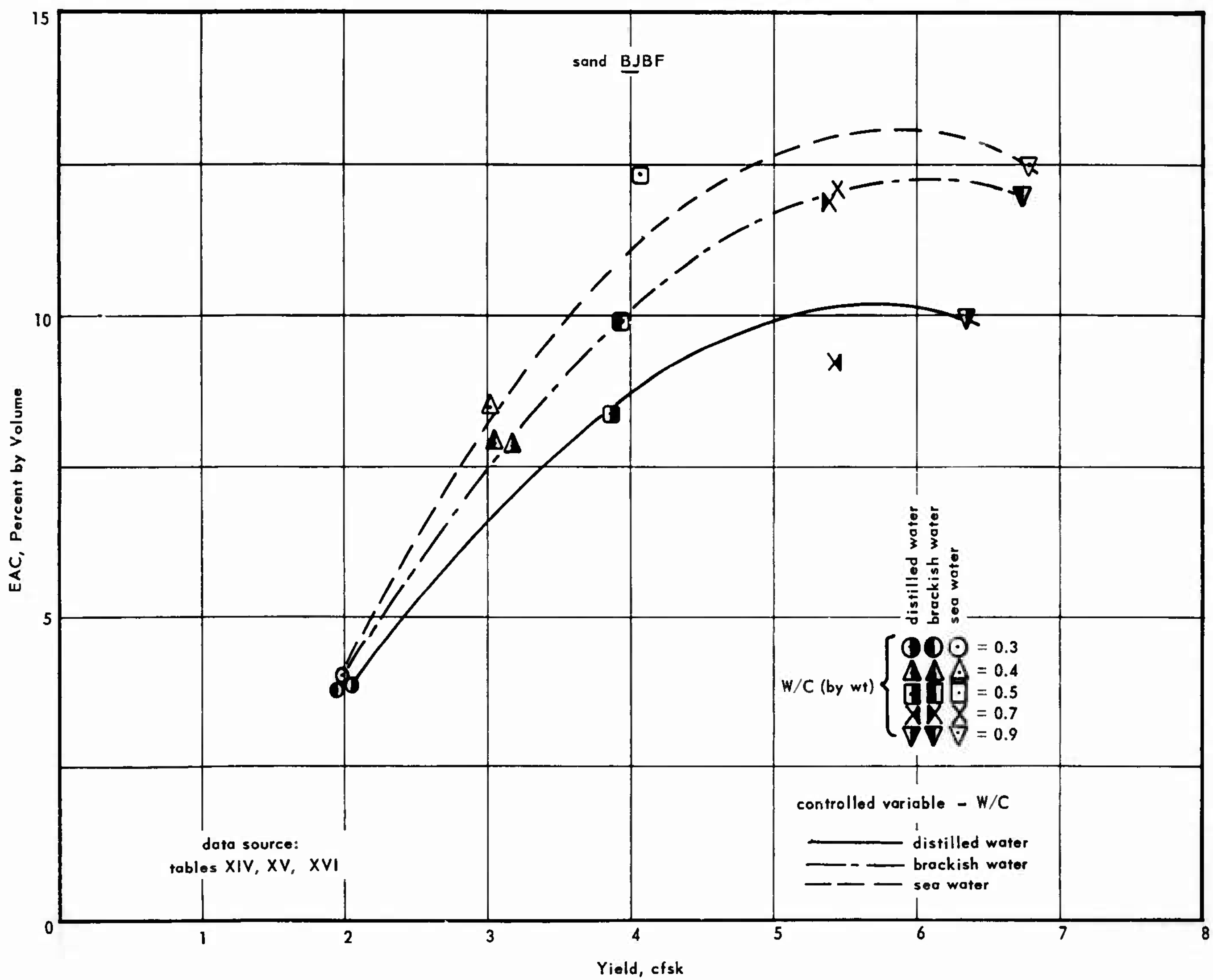

Figure 34. Correlation 2i-b'.

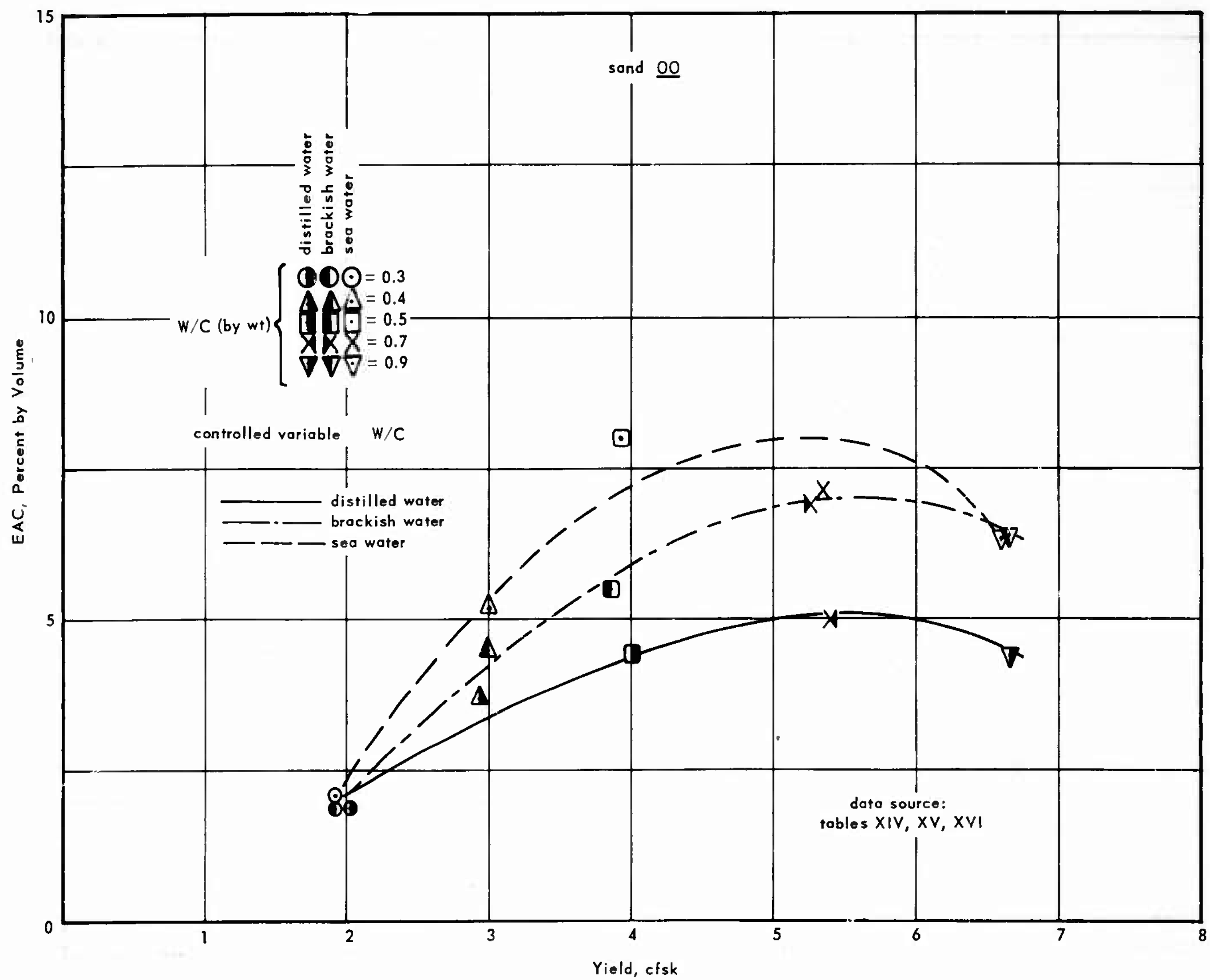

Figure 35. Correlation 2i-b'.

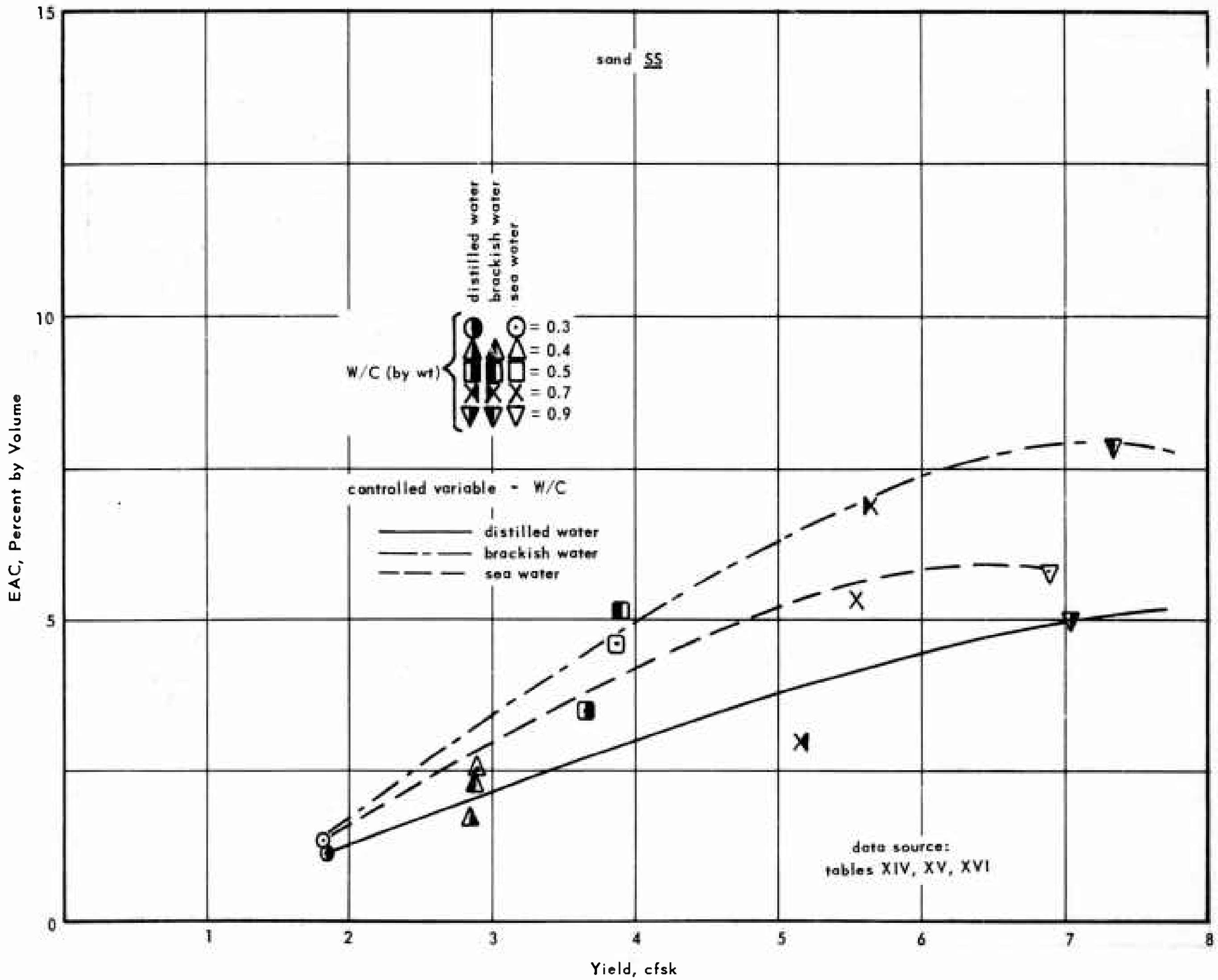

Figure 36. Correlation 2i-b'.

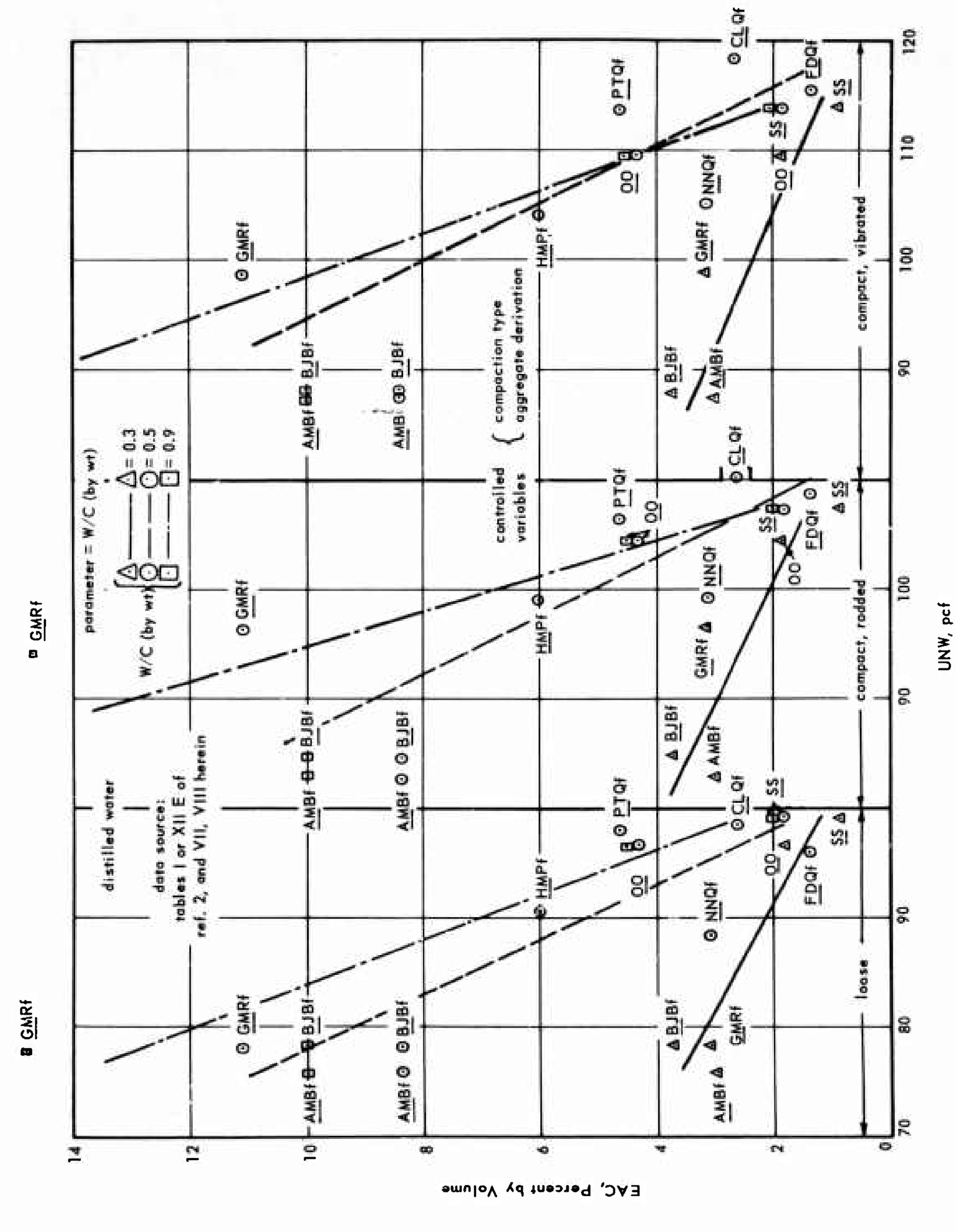

Figure 37. Correlation 3a-a'.

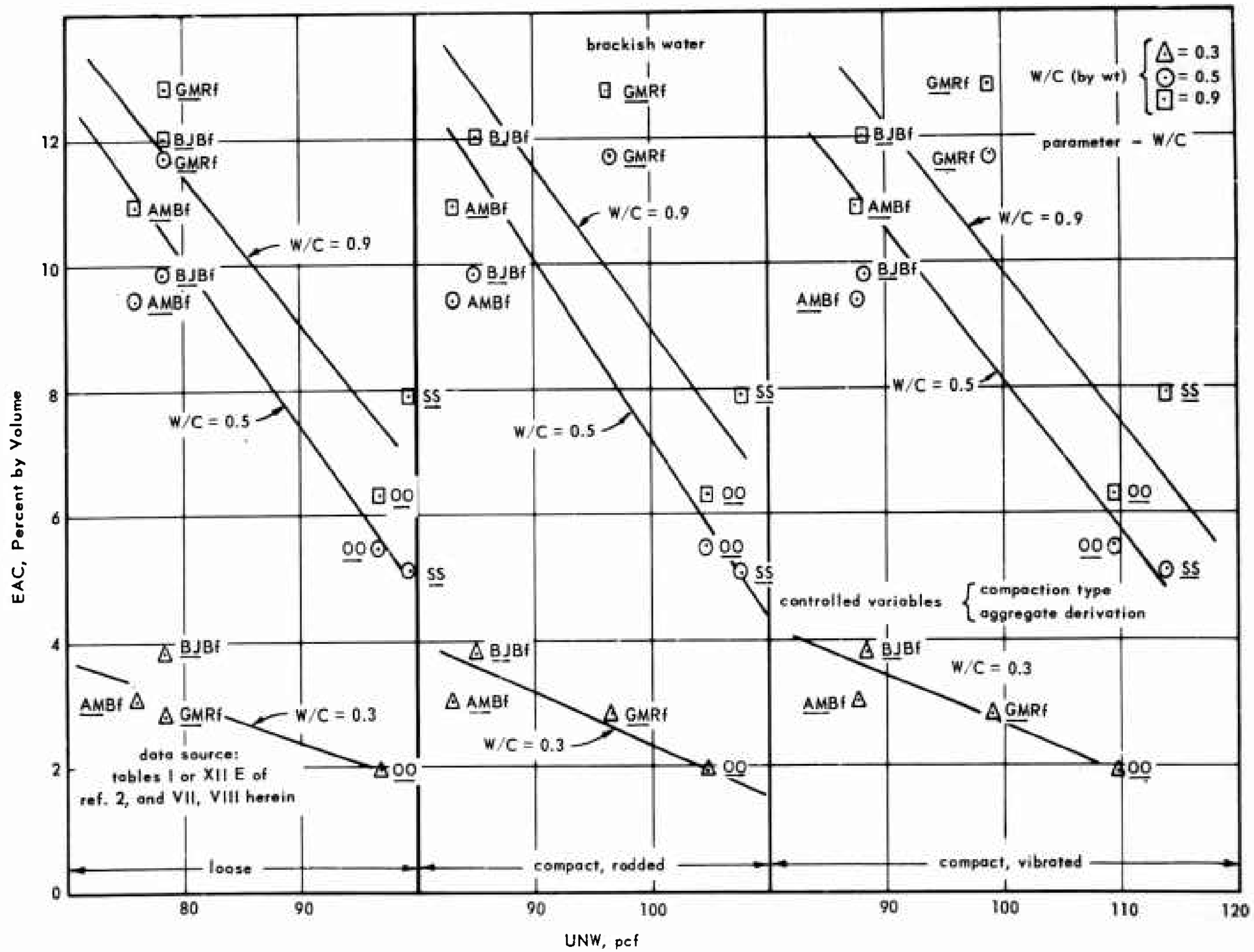

Figure 38. Correlation 3a-a'.

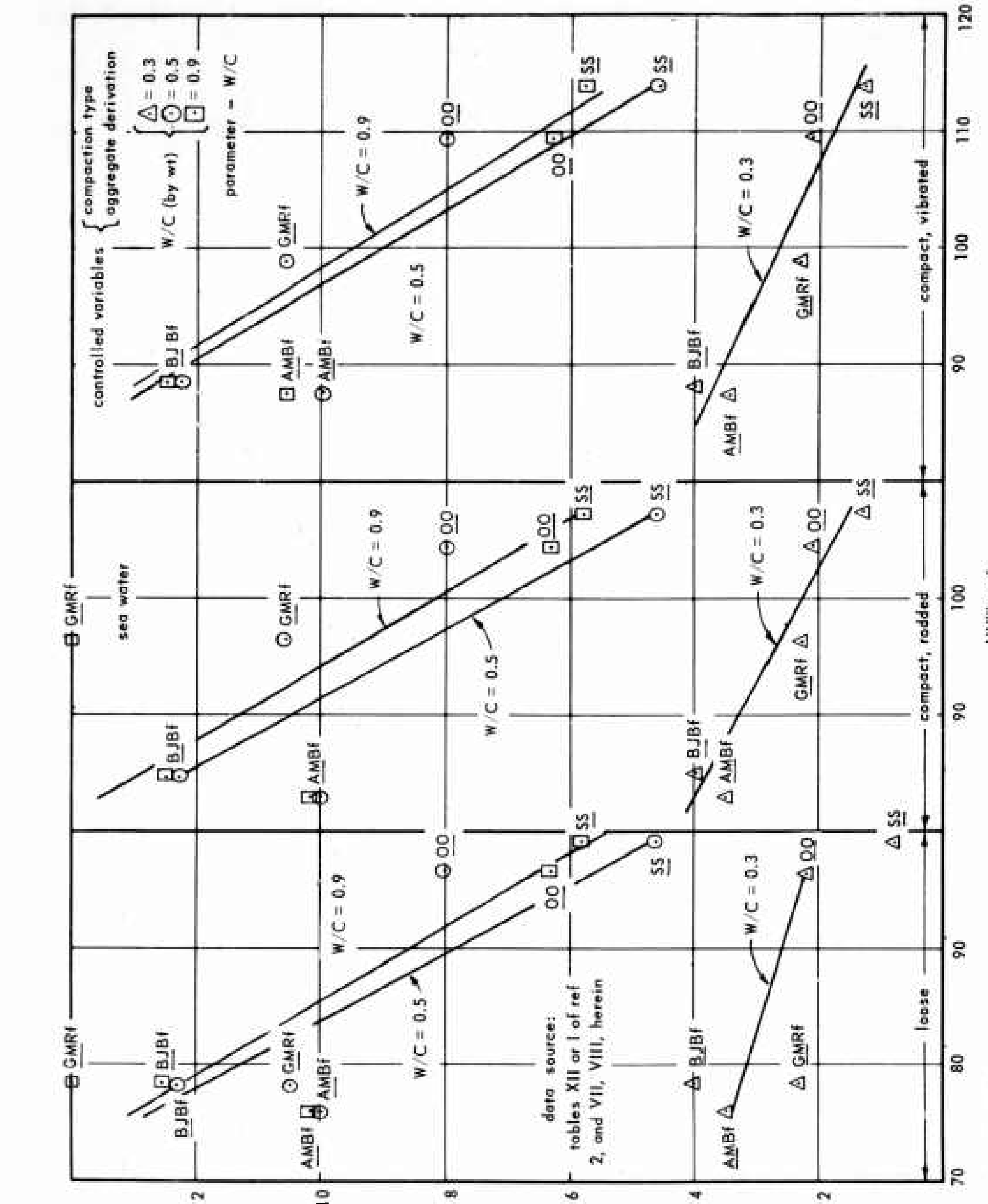

Figure 39. Correlation 3a-a'.

Correlation 3a-b'.

The relationship between mortar UWP and sand UNW is depicted by Figure 40, which serves to indicate that type of water is an insignificant influence. All three families of curves seem to approach asymptotically, or possibly converge at, some hypothetical maximum; this trend might be expected were the sand UNW values purposely increased very appreciably, as in the case where a heavyweight mortar would be required in conjunction with masonry shields constructed for protection against nuclear radiation. It is obvious from Figure 40 that coral beach-sand mortars in the plastic state normally are the lightest in weight by virtue of their relatively low UNW values and regardless of W/C involved. It is also evident that as the W/C approaches a minimum the UWP of such beach-sand mortars will be equal practically to the UWP values of mortars incorporating coral reef sand or reference sand.

Correlation 4a-a'.

Figure 41 shows the EAC variation obtained with W/C values that range from 0.3 to 0.9. At extremely low W/C values the EAC of coral mortars (B- or R-derived sands) is about twice that of reference mortars, regardless of type of water used, and for the mixes investigated the maximum EAC (corresponding to this W/C value) is never greater than 4 percent. At the other extreme, for W/C values of 0.9 the EAC of coral sand mortars depends greatly upon the derivation of the sand and upon the type of water employed in the mortar. Mortars made with R-derived coral sands tend to have equal EAC at any W/C between 0.3 and 0.9, regardless of whether sea water or distilled water is employed. Mortars incorporating B-derived coral sands exhibit as much as 3 percent more EAC (at W/C of 0.9) when sea water instead of distilled water is used; the behavior of reference mortars in this respect is very similar. As a rule, at high W/C values mortars fabricated with R-derived coral sands will exhibit about three times the EAC of reference mortars and nearly twice the amount of EAC obtainable with B-derived coral sand mortars.

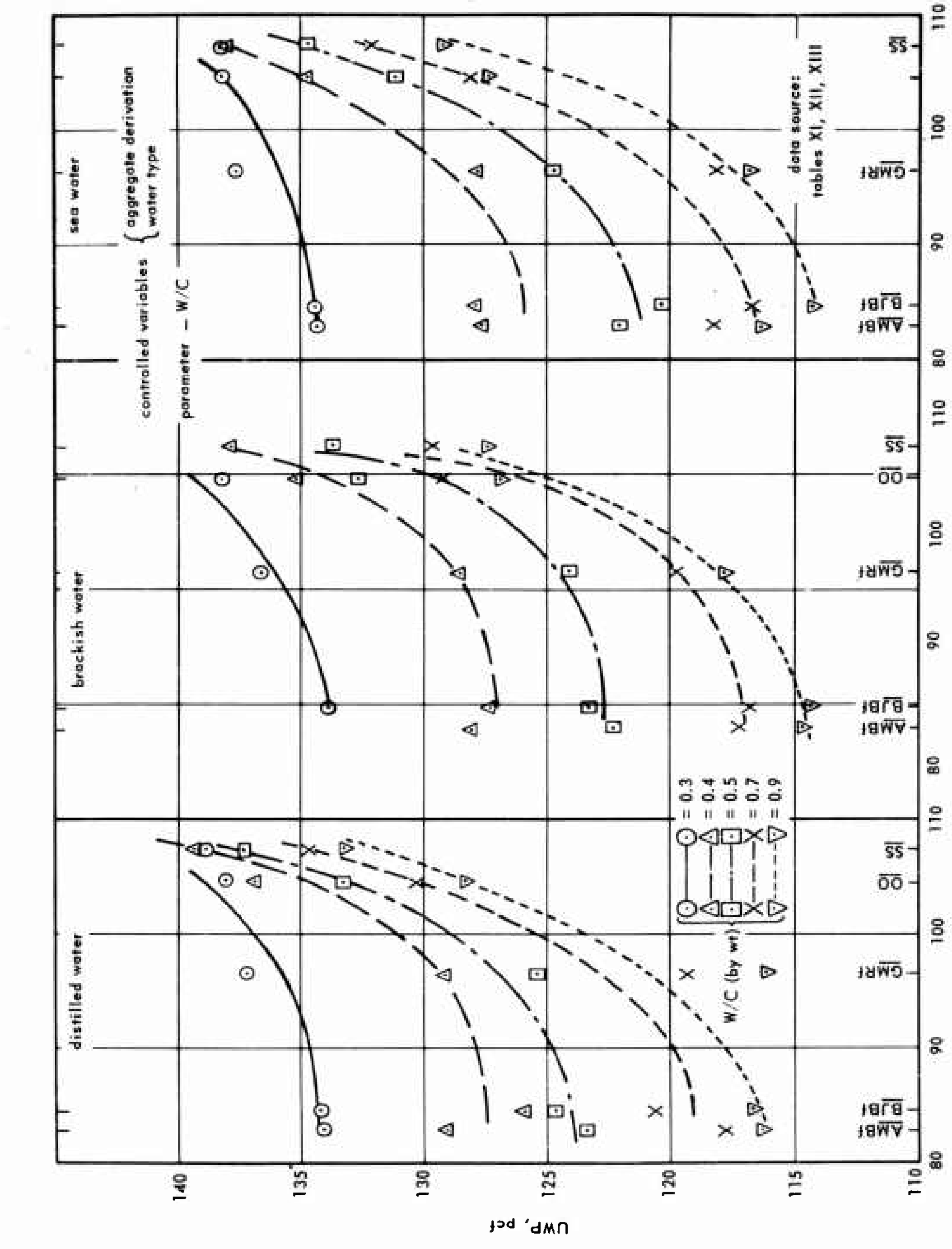

Figure 40. Correlation 3a-b'.

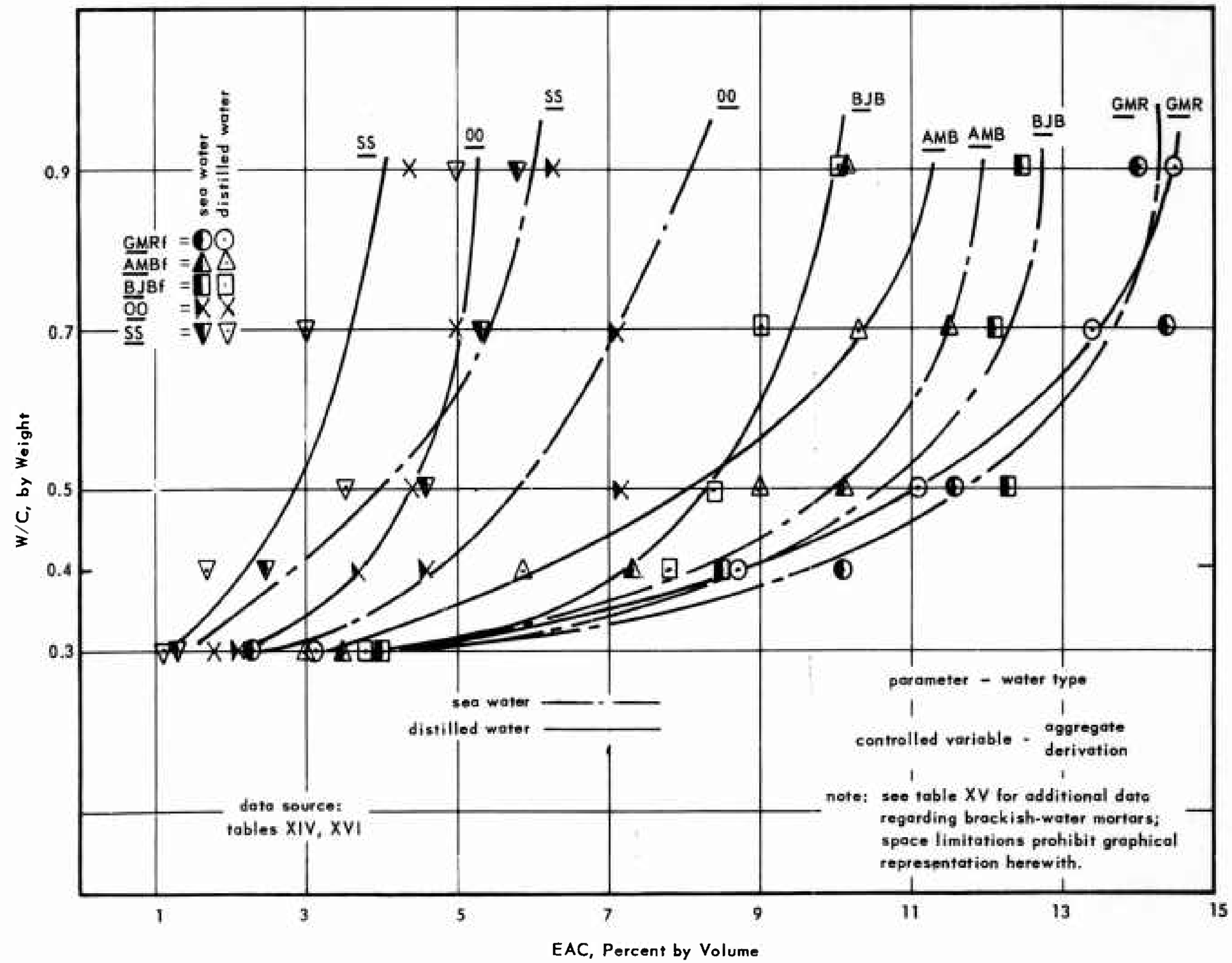

Figure 41. Correlation 4a-a'.

CHAPTER 6 END NOTES

6.1 Shown in Table I as Correlations 2f-a' and 2h-a', respectively.

6.2 Symbols for identifying aggregate sources are defined in Table II.

6.3 Symbols, for abbreviating descriptive terminology concerning physical characteristics of aggregates and mortars, are defined in Section 1 (pp. 6-7) and Section 3 (pp. 11-13).

Chapter 7

MORTARS IN THE SOLID STATE

20. PRELIMINARY CONSIDERATIONS

As pointed out in the Introduction, the objective is to analyze the laboratory results as a means of demonstrating how various factors affect the physical characteristics of hardened coral mortars.

Despite the accepted principle that sand gradation exercises an appreciable influence upon the workability of the mortar, it is impossible to determine whether or not FM is a reliable index of the flexural or compressive strength values attained with the various mortars considered in this project. This fact is indicated in Section 2 and statements elaborating the topic are found in Section 8.

21. INTERPRETATION OF OBSERVATIONS

Correlation 5a-a'.

Examination of data in Tables XI, XII, and XIII, and correlation thereof with data in Table IA of Reference 2, discloses that the variation of sand voids (rodded condition) with BUD (bulk density of mortar in the solid state) of mortars (later fabricated with those sands) is nearly constant regardless of age of the hardened mortar and regardless of type of water employed. If data representative of B- and R-derived coral mortars are plotted, using mortar BUD as the ordinate and sand voids (rodded) as the abscissa, and using age and sand derivation as the controlled variables with water type as the parameter, one finds that the straight lines passing among the various plotted points slope approximately 45 degrees downward to the right. Regardless of age (i.e., 1, 7, 28, 91, or 364 days) and regardless of water type, the variation of sand voids with mortar BUD is rather constant when the W/C is 0.3; an increase of 15 percent voids of the sand (in rodded condition) reflects a decrease of about 5 percent in BUD of the hardened mortar. Figure 42 illustrates the variation, at age 28 days, of the sand voids-mortar BUD ratio with W/C values used in this investigation.

Correlation 5b-a'.

The variation of W/C with BUD of hardened mortar scarcely is affected by the type of water involved; this is evident from the tabulated data and is illustrated in Figures 42 and 43. In general, for the coral mortars investigated in this program, the curves in Figure 43 serve as fair criteria of the rates of reduction in BUD to be expected with increase in W/C values.

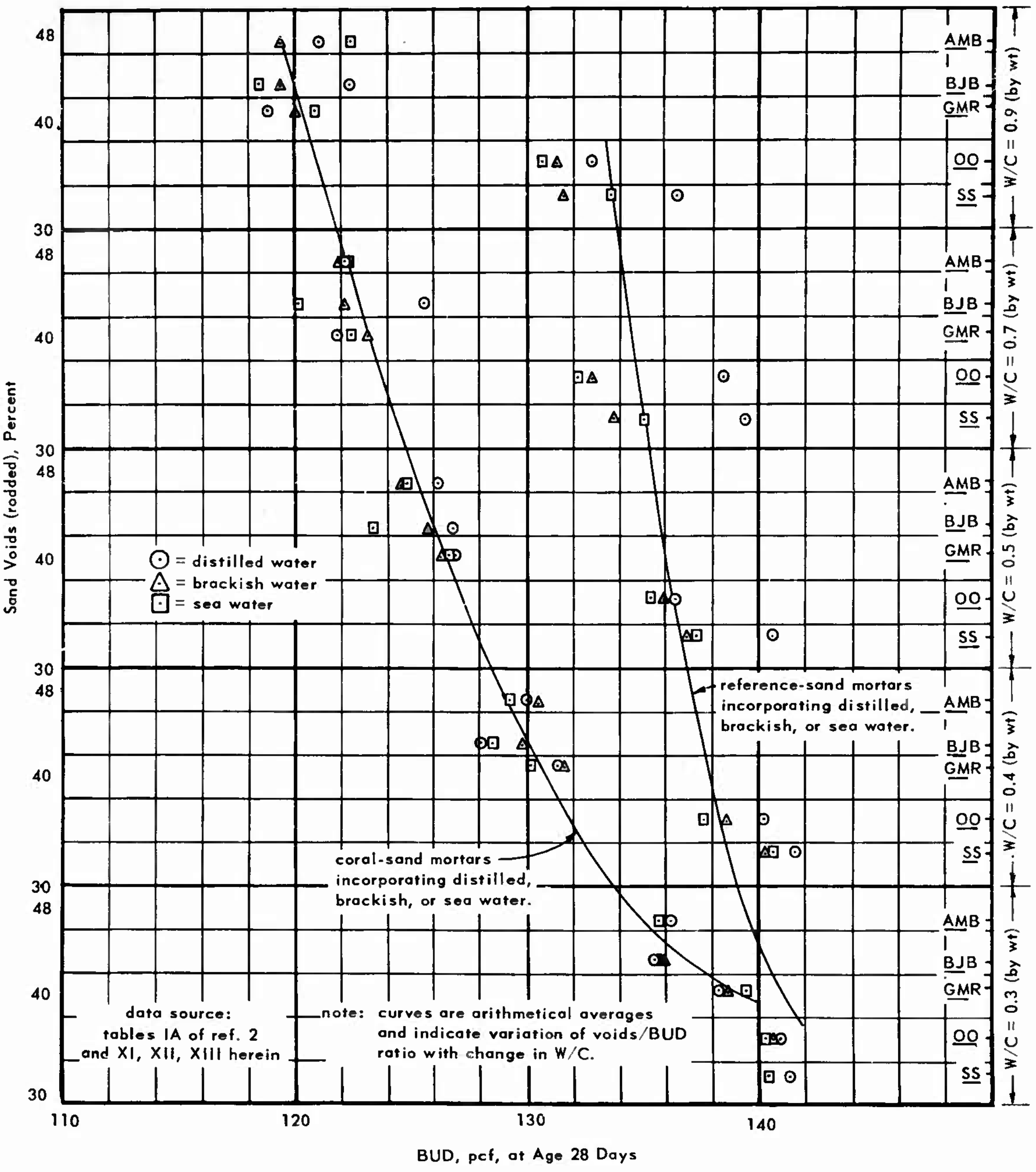

Figure 42. Correlation 5b-a'.

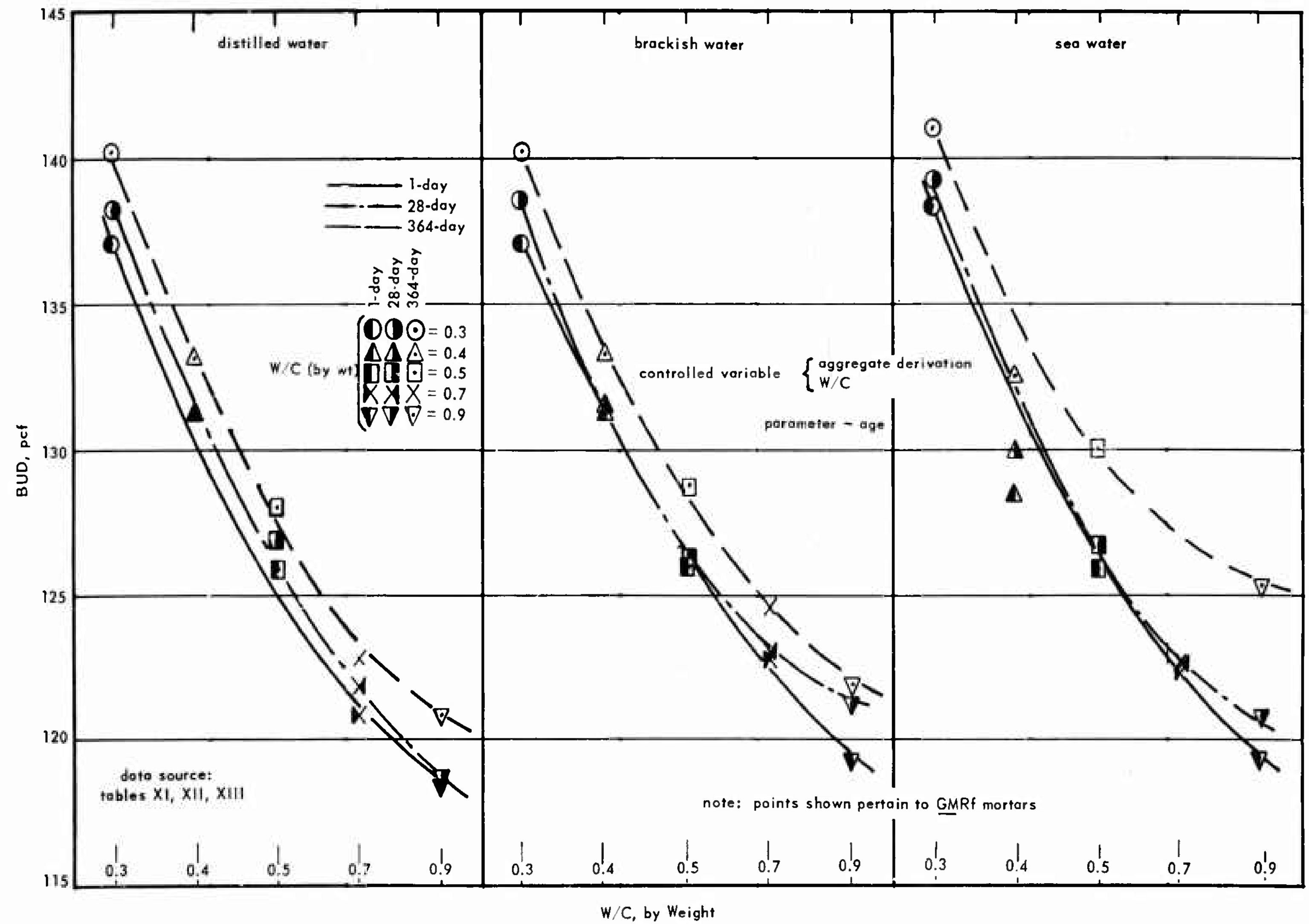

Figure 43. Correlation 6a-a'.

Correlation 6a-a'.

The relationship between water type and mortar BUD is typified by a study of plotted test data for mortars incorporating GMRf sand. Figure 43 illustrates clearly the absence of any practical relationship between these two factors. Furthermore, age of the mortar causes no appreciable departure from the trends shown.

Correlation 6b-a'.

Not evaluated for reasons stated in Section 2.

Correlation 6c-a'.

As expected, increased EAC results in decreased BUD values; this trend is typified in Figure 44 for 28-day-old mortars fabricated with distilled water and three derivations of sand and involving W/C values ranging from 0.3 through 0.9. The data in Tables XII and XIII serve to substantiate the observation that age and water type exert little influence upon the manner in which EAC and BUD are related.

Correlation 7a-a'.

The effect of water type upon the VCH (volume change of mortar during the transition from the plastic to the solid state) characteristics of coral mortars is delineated in Figure 45. All specimens, except those made with GMRf and sea water, exhibit an increase in volume during the initial 28 days of storage. The use of distilled water causes a swelling that reaches maximum value at about two months age after which shrinkage occurs at a rate such that at age one year the VCH approaches the value first observed at age one day. The use of sea water is comparable insofar as swelling and subsequent shrinkage are concerned but the magnitudes corresponding to any particular age (from one day to one year) are somewhat less than result with distilled water. When brackish water is employed in the mix the hardened mortar swells measurably to age one month after which time shrinkage occurs. Curing and storage conditions in all instances are as explained in Section 6. It is evident, from Tables XIV thru XVI and Figure 45, that when the choice of water type is limited (as usually is the case where construction involves coral) mortars fabricated with sea water and R-derived coral sand are apt to exhibit the smallest range of swelling and shrinkage. The data indicate, too, that the ranges of average VCH attained with mortars incorporating sea water are of lesser magnitudes (regardless of sand derivation) than exhibited by similar mortars involving brackish or distilled water.

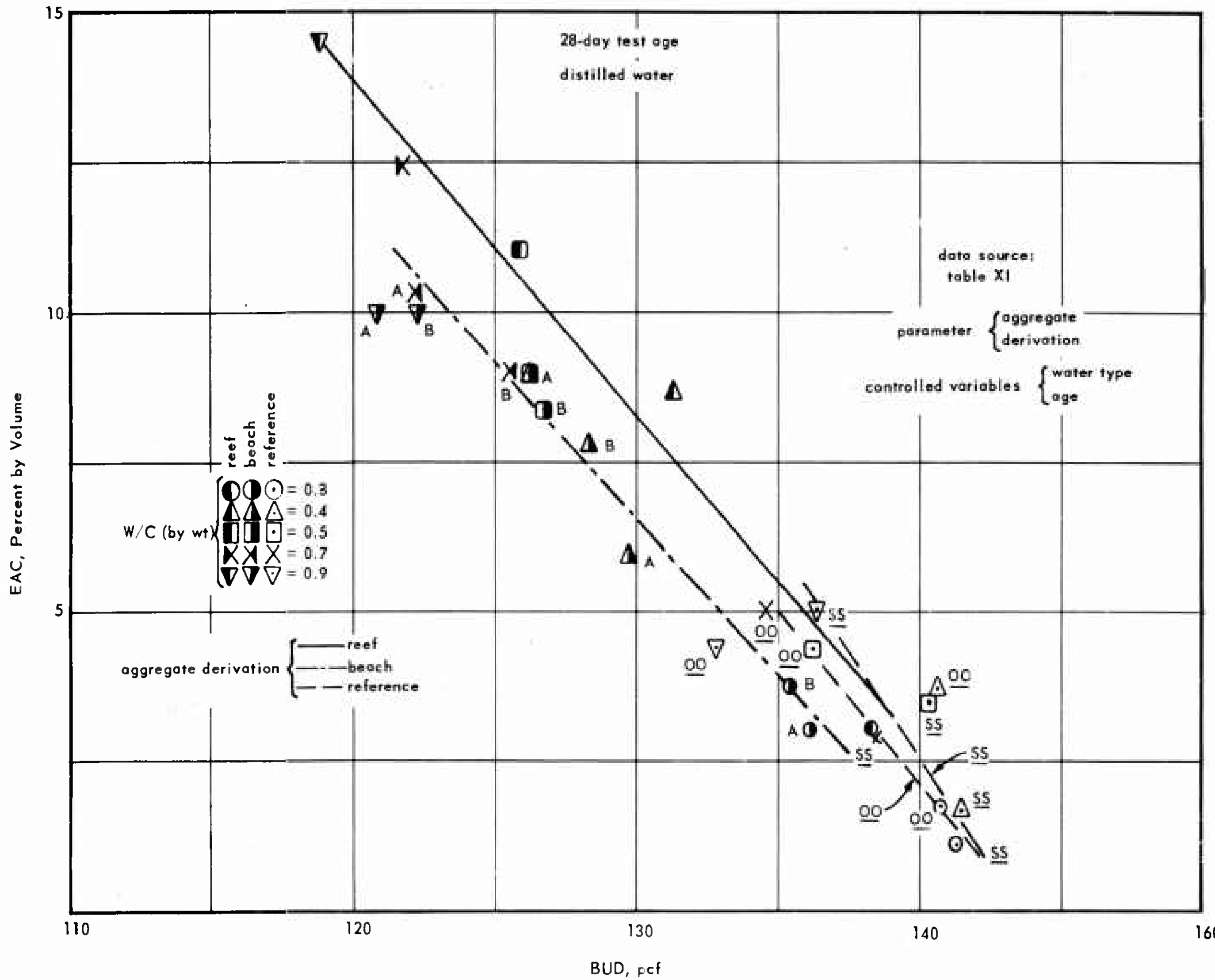

Figure 44. Correlation 6c-a'.

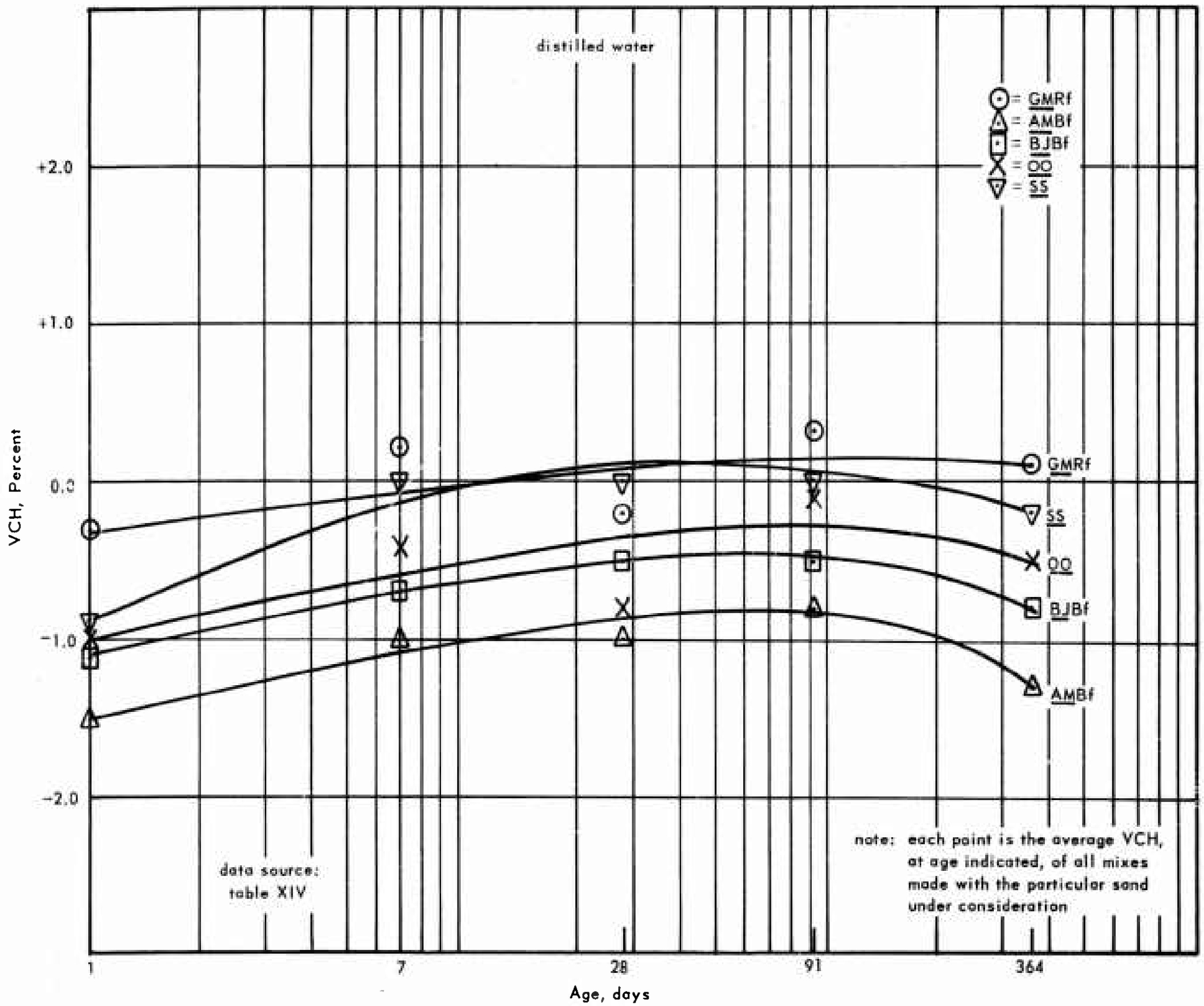

Figure 45. Correlation 7a-a'. (Part 1 of 3)

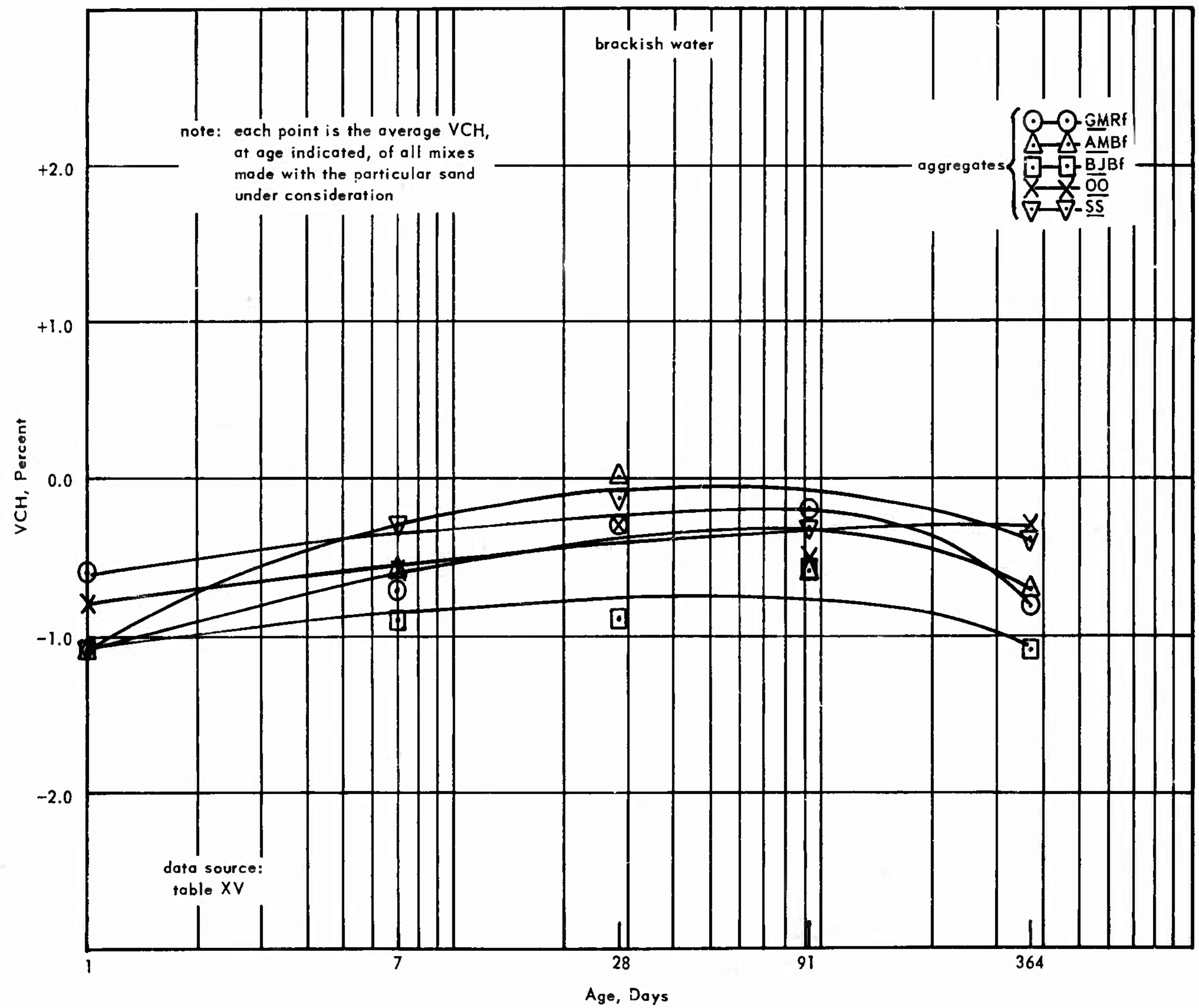

Figure 45. Correlation 7a-a'. (Part 2 of 3)

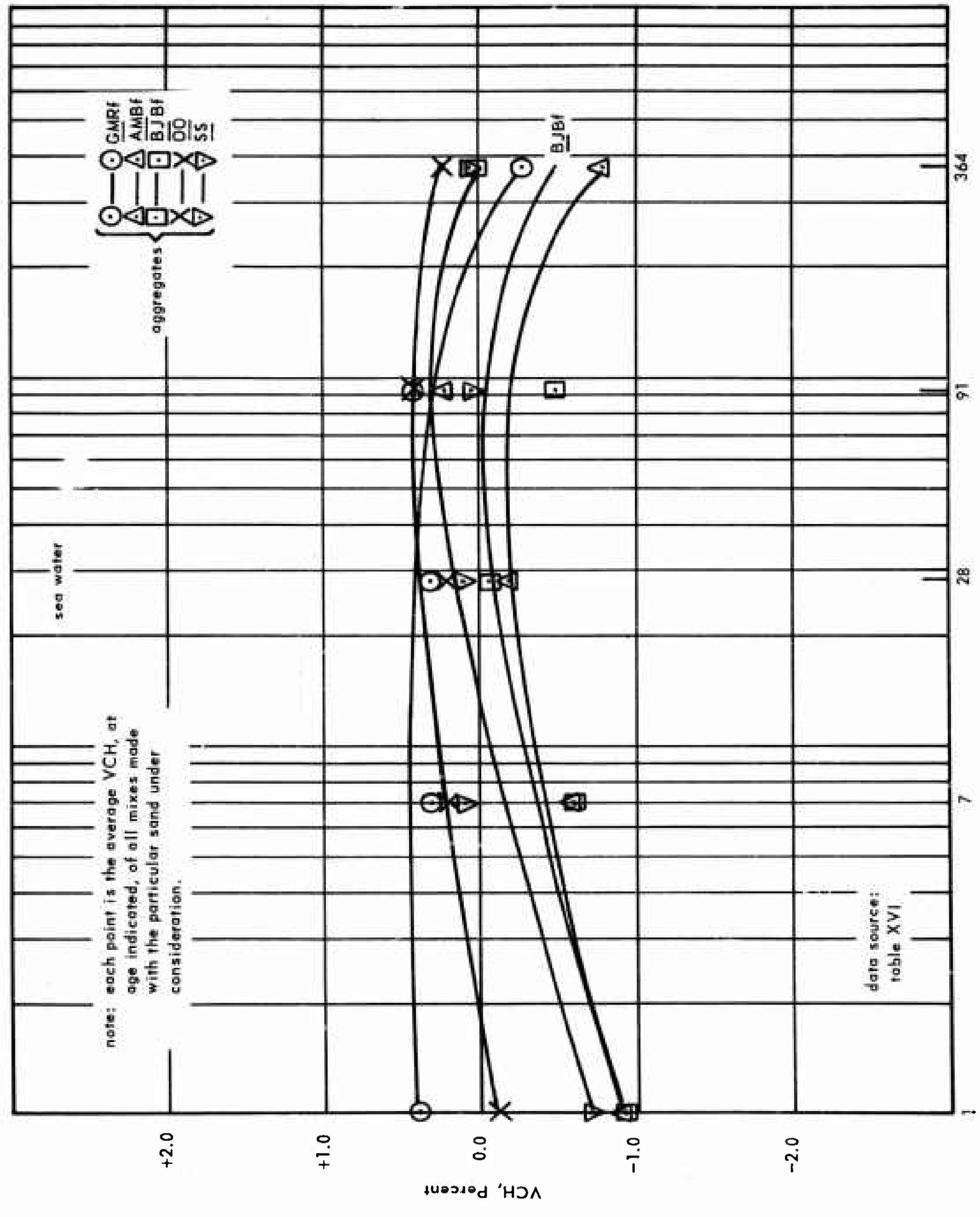

Figure 45. Correlation 7a-a'. (Part 3 of 3)

Correlations 7b-a', 7c-a', and 7d-a'.

Not evaluated for reasons stated in Section 2.

Correlation 7e-a'.

Tables XIV, XV, and XVI show that the smaller the W/C the smaller the shrinkage; this is apparent for all mortars investigated, regardless of sand derivation and water type. Considering that the majority of shrinkage occurs in the cement paste, a lesser amount of water associated with cement assures a greater compaction of paste structure and a resultant decrease in mortar shrinkage. The lean mixes (i.e., low CMC) require high W/C to insure a flow of 100±5 percent; this, of course, creates a paste of comparatively inferior quality. It is accepted that loss of water from the hydrating cement gel causes shrinkage; but the mortar specimens were stored continually under moist conditions and therefore slight swelling rather than shrinkage occurred with increased age or storage time. This is apparent generally upon study of the VCH data presented in Tables XIV, XV, and XVI.

Correlation 7f-a'.

As shown in Figures 46, 47, and 48, B-derived coral sand mortars made with distilled water nearly always shrink with increasing EAC whereas R-derived sand mortars may or may not undergo negative VCH. Whether or not such performance is an indication of EAC influence is problematic because the effect of W/C cannot be separated in the case of these data. B-derived coral sand mortars and reference sand mortars that are compacted by vibration exhibit shrinkage (see Figures 49 and 50) in nearly every instance regardless of percent EAC; again, the true effect of EAC is obscured by the powerful influence of W/C relative to negative VCH and by the mechanics of vibration relative to bleeding of excess water. Hand-tamped specimens of B-derived coral sand mortar demonstrate (Figure 47) maximum swelling at all ages when sea water is incorporated in the mix and the approximate EAC is 8 percent; similarly compacted specimens of R-derived coral sand mortar show (Figure 48) maximum swelling at all ages when sea water is used and the approximate EAC is 2 percent. Study of the data in Tables XIV, XV, and XVI indicates that reference sand mortars fluctuate with regard to positive VCH and thus no distinct trends can be expected.

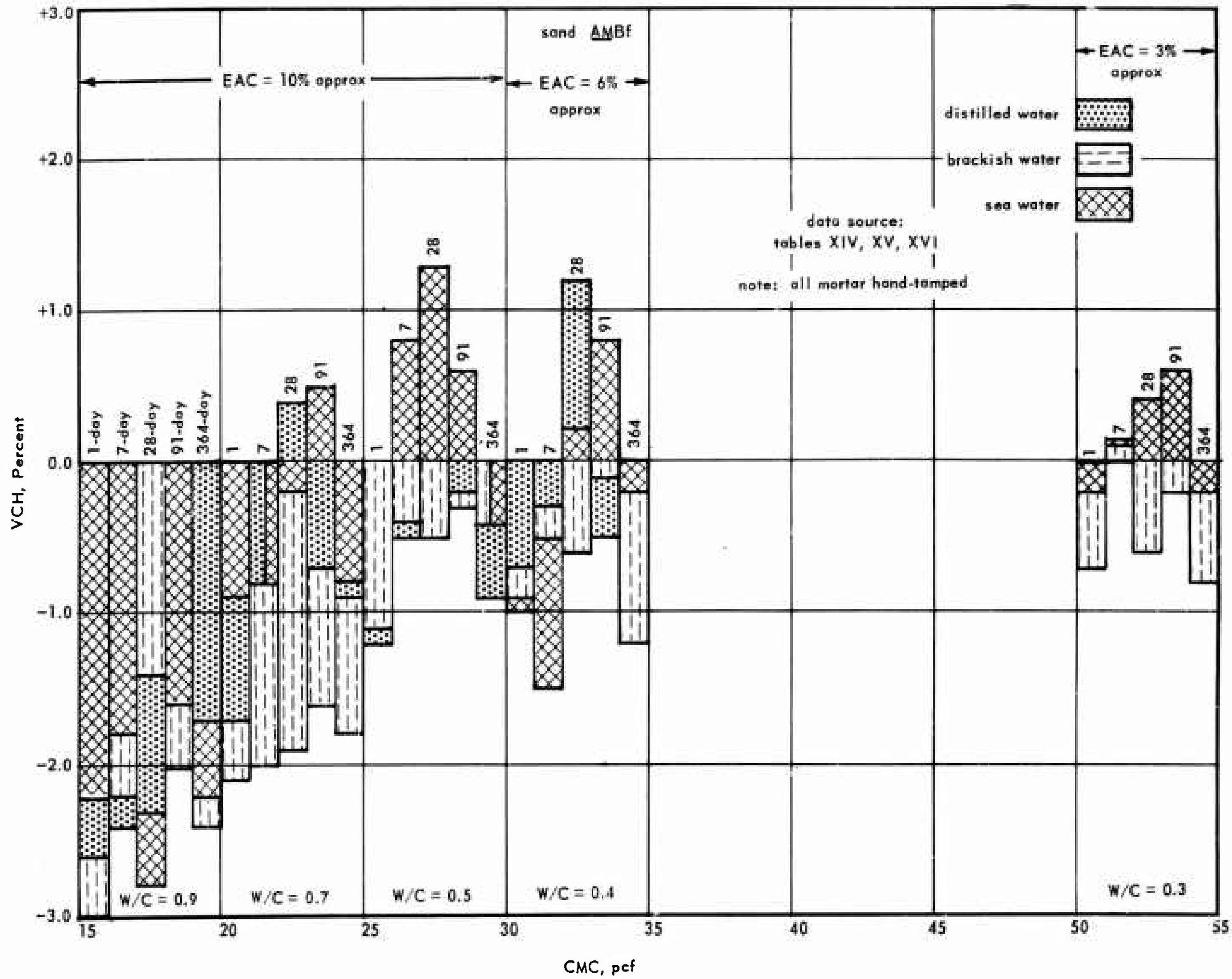

Figure 46. Correlation 7f-a'.

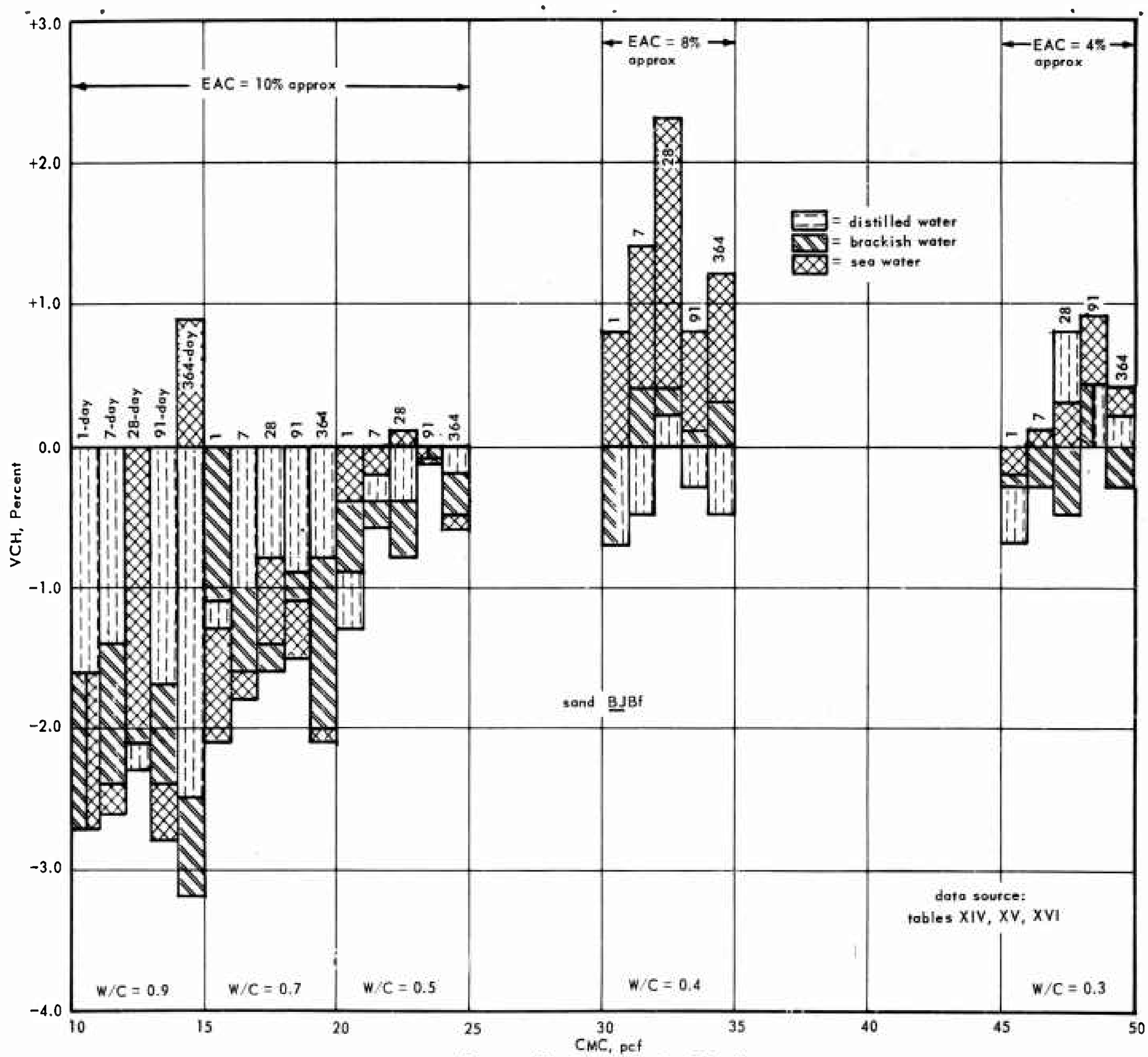

Figure 47. Correlation 7f-a'.

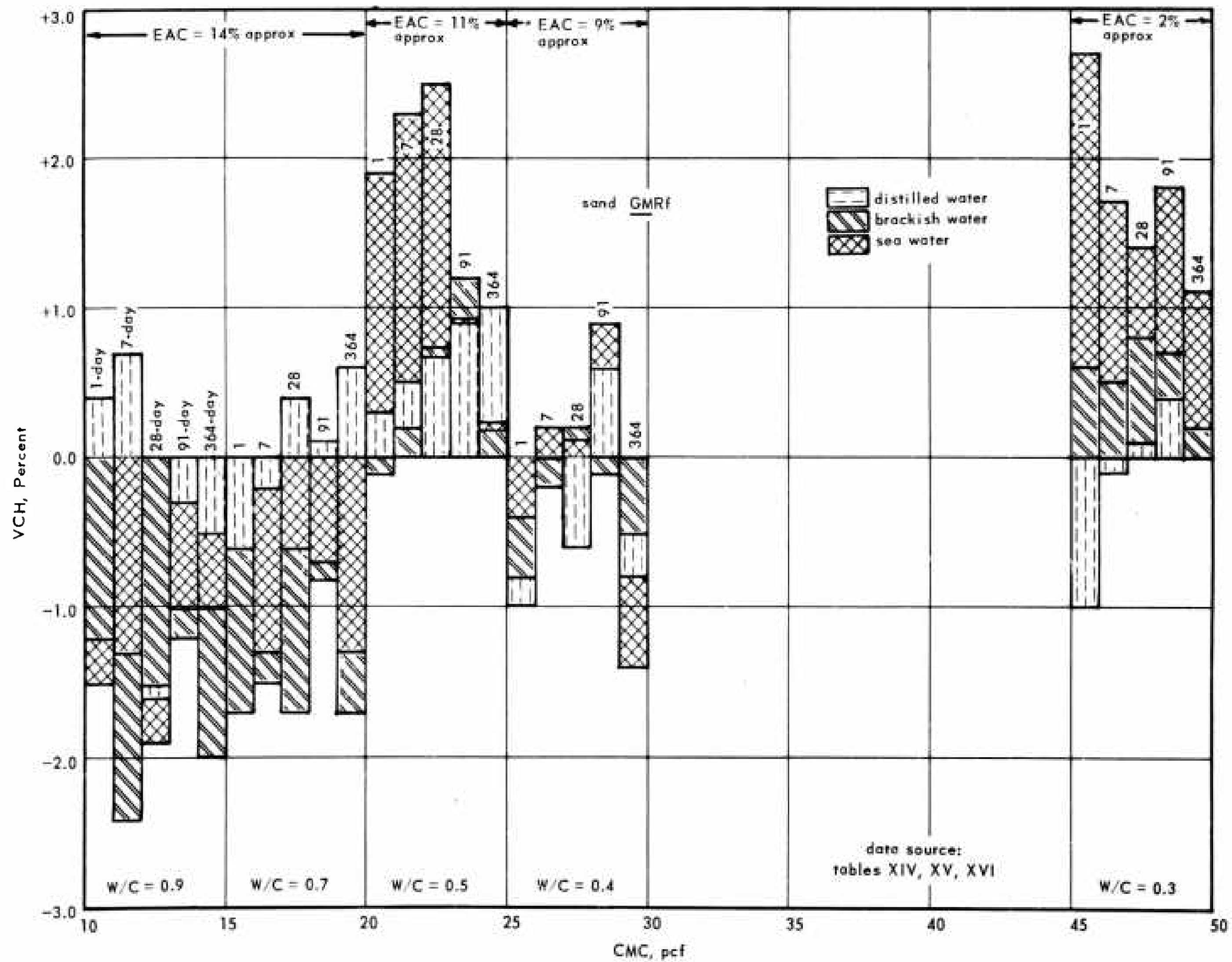

Figure 48. Correlation 7f-a'.

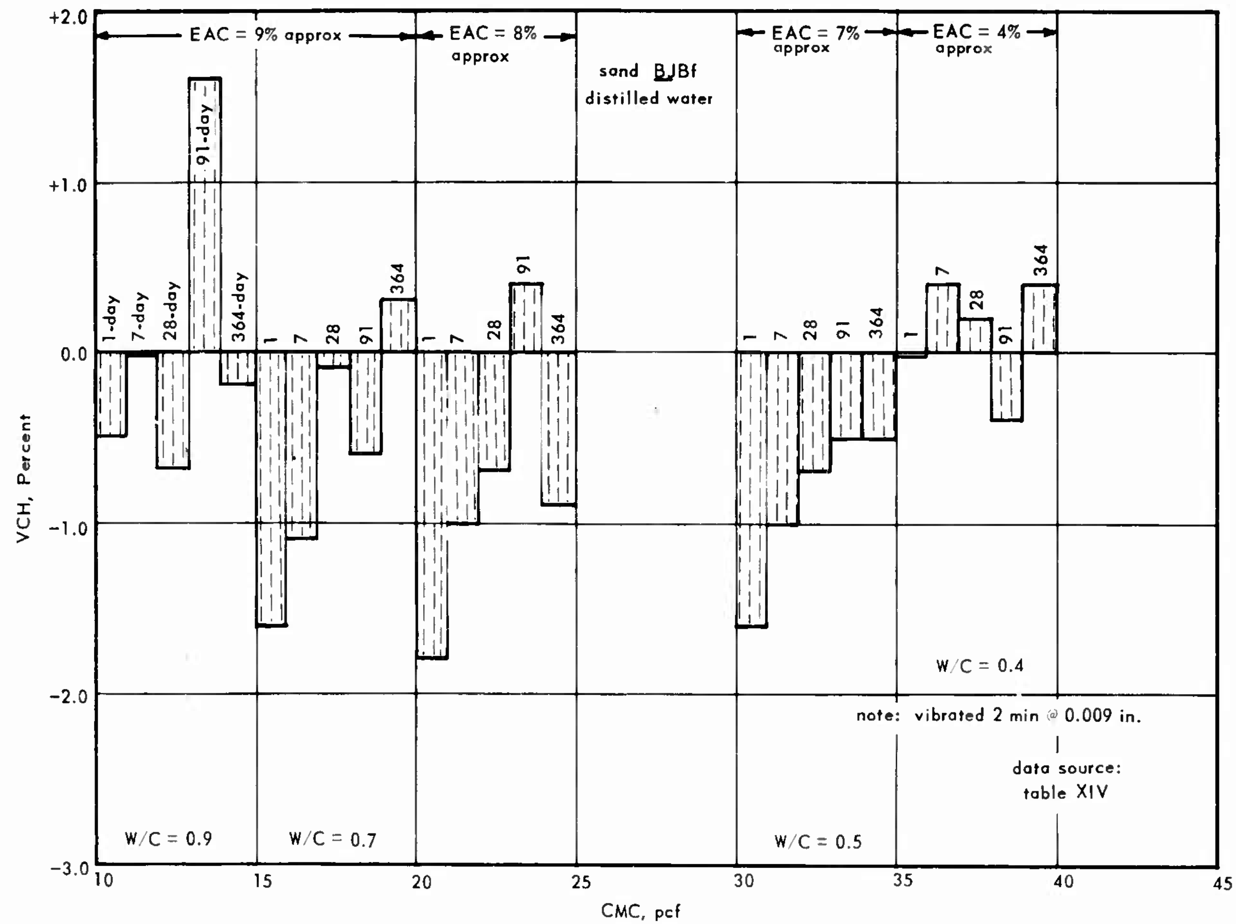

Figure 49. Correlation 7f-a'.

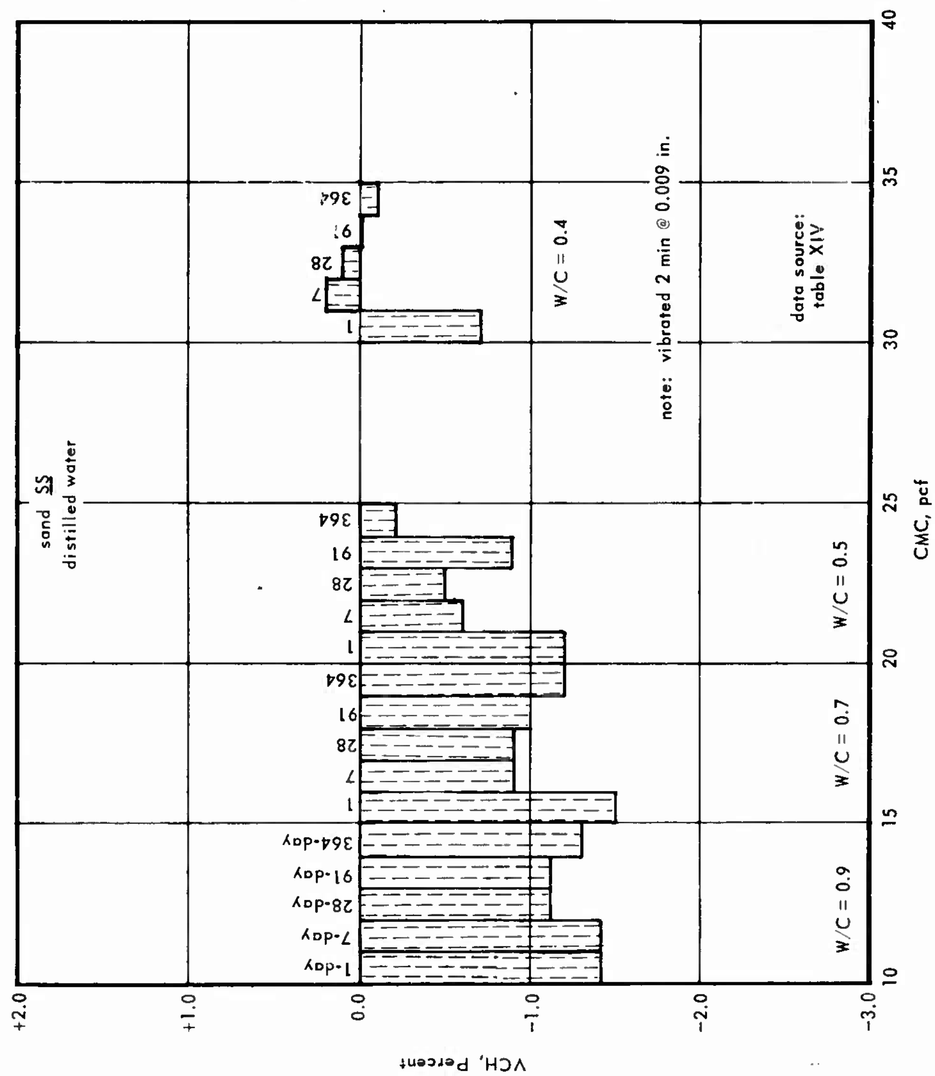

Figure 50. Correlation 7f-a'.

Correlation 7a-b'.

Irrespective of sand derivation, at age one year the mortars generally exhibit the greatest weight increase when sea water has been incorporated in the mixes. Tables XIV, XV, and XVI serve to verify this observation. Figure 51 portrays this trend with respect to mortars fabricated with a typical coral reef sand. Also refer to correlation 7e-b'.

Correlations 7b-b', 7c-b', and 7d-b'.

Not evaluated for reasons stated in Section 2.

Correlation 7e-b'.

Examination of the data in Tables XIV, XV, and XVI indicates that, regardless of water type and aggregate derivation, increase in W/C creates increase in WCH (weight change of mortar during the transition from the plastic to the solid state) of the hardened mortar. Simultaneously, for any W/C there occurs generally a positive WCH of the mortar with increasing age, irrespective of type of water or derivation of sand. These trends are identical to those observed in correlation 4a-b'. All these specimens were cured and stored under moist conditions (refer to Section 6).

Correlation 7f-b'.

Mortar specimens, fabricated with distilled water and BJBf sand, and which have been compacted by vibration and contain slightly more than 9 percent EAC, at any age not beyond one year exhibit from three to five times the increase in weight displayed by companion mixes containing approximately 4 percent EAC. When the same B-derived coral sand mortars, compacted by hand-tamping, are compared relative to WCH (as shown in Table XIV) it is found that mortars containing 11 percent EAC also exhibit from three to five times the positive WCH displayed by companion specimens containing nearly 4 percent EAC. Study of WCH data for hand-tamped AMBf mortars indicates that when the EAC is increased from 3 to 10 percent the WCH ratio is about 2 to 4. Comparison of data in Tables XIV, XV, and XVI indicates that these approximate relations are not appreciably different when other water types are employed in the mortars despite the statement in correlations 7a-b'. As a rough guide for B-derived coral sand mortars, when the EAC is doubled the resultant WCH increase is quadrupled; for R-derived coral sands, when the EAC is increased five times the resultant WCH increase is tripled.

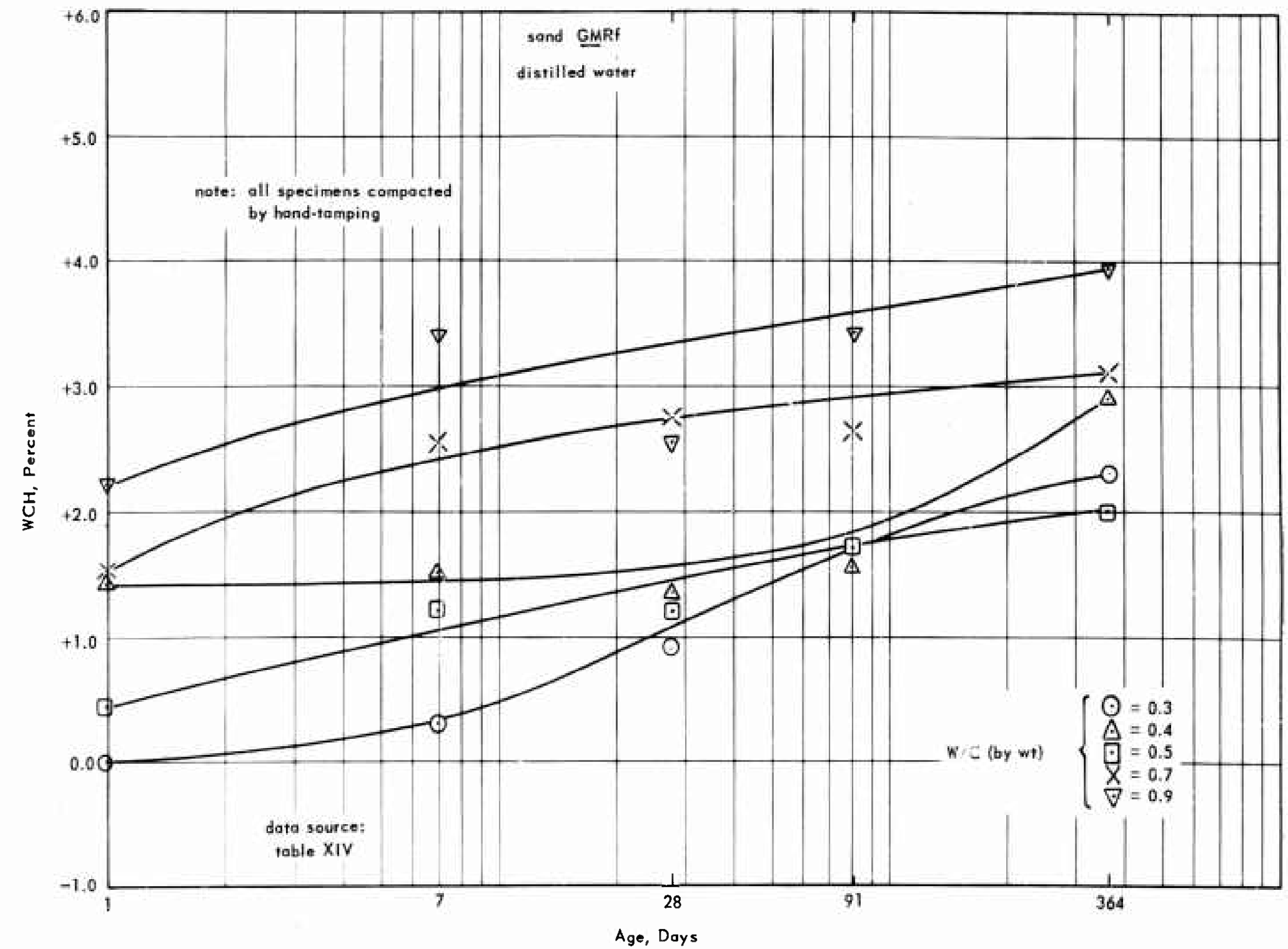

Figure 51. Correlation 7a-b'. (Part 1 of 3)

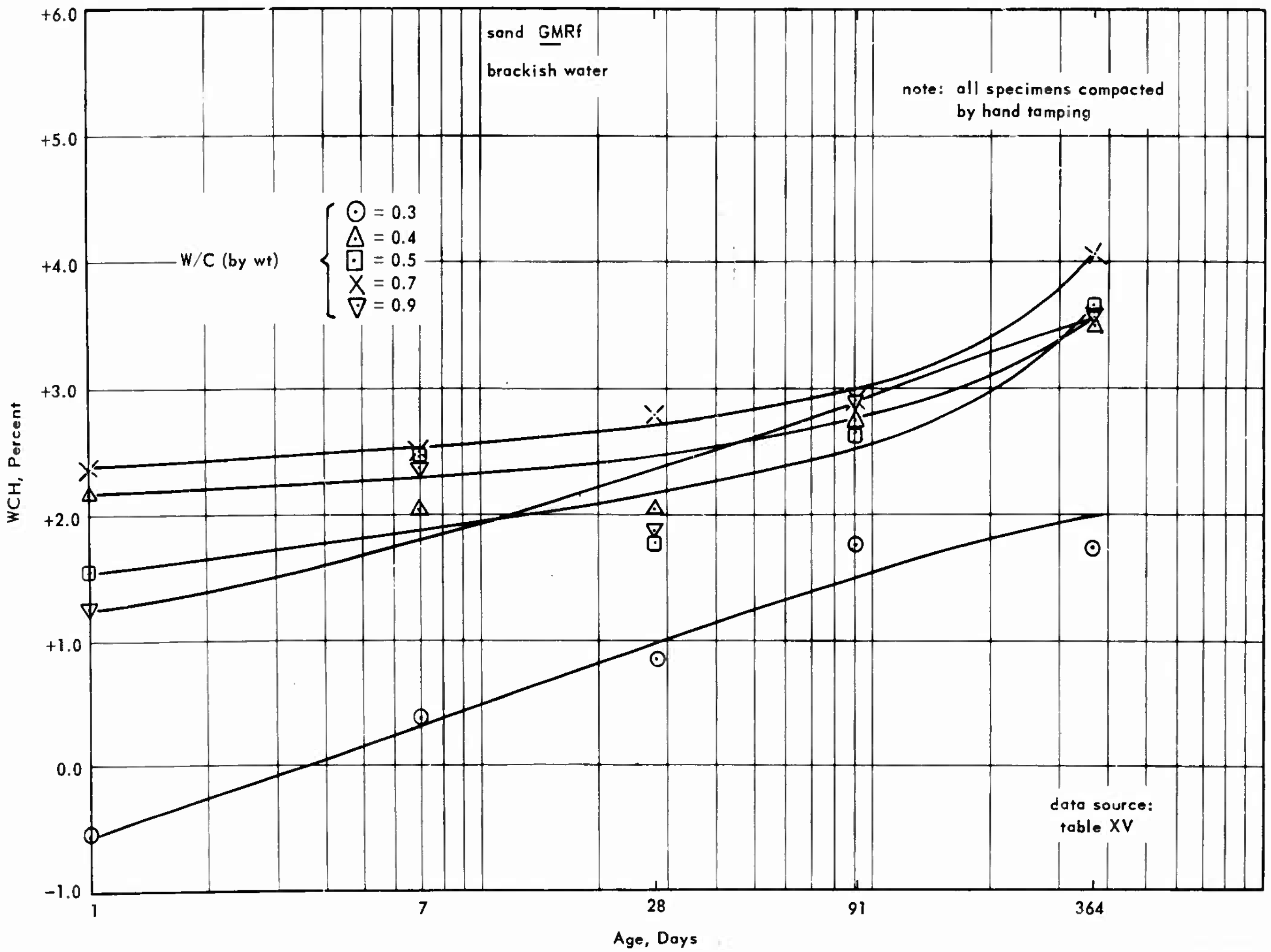

Figure 51. Correlation 7a-b'. (Part 2 of 3)

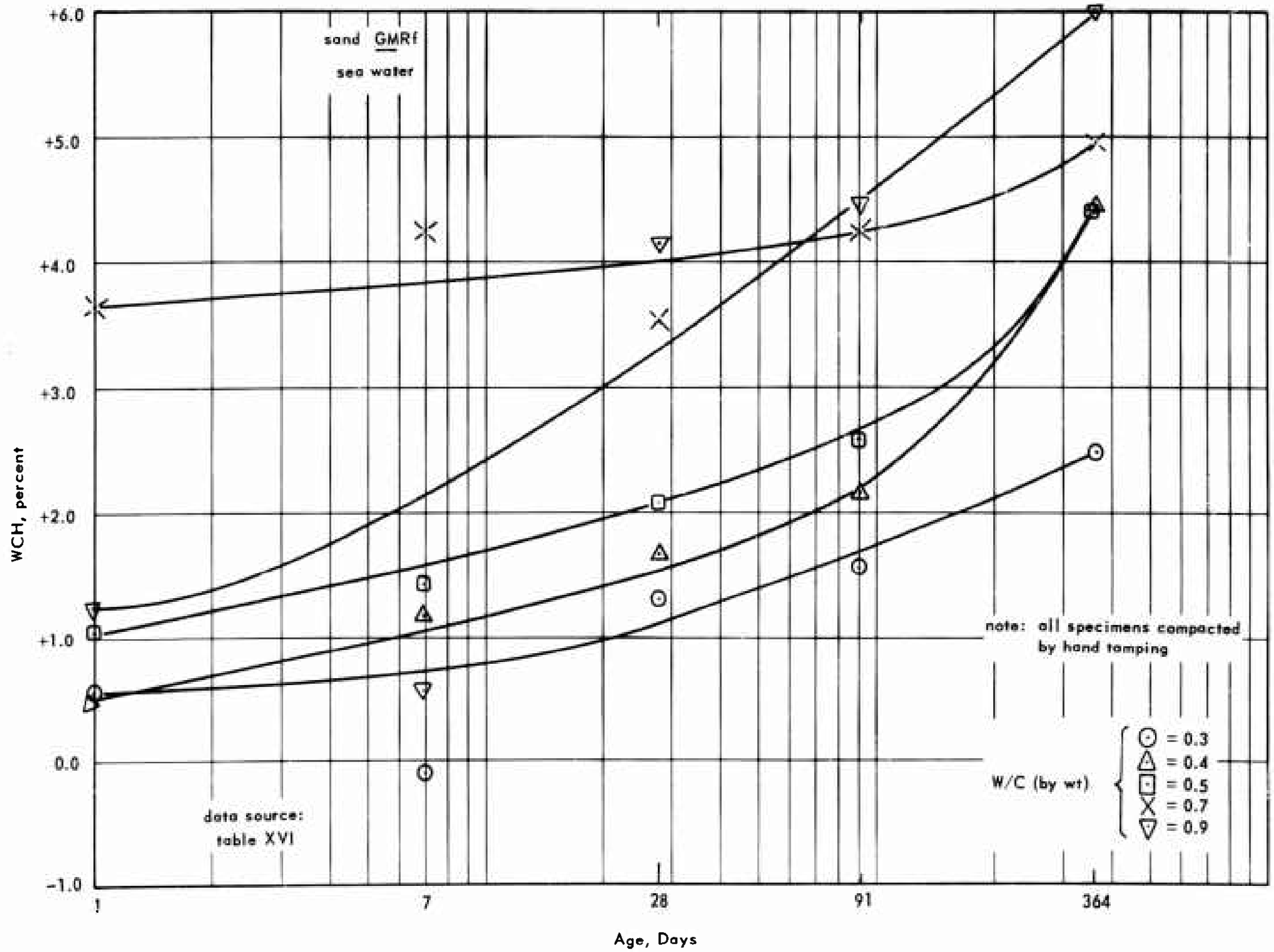

Figure 51. Correlation 7a-b'. (Part 3 of 3)

Correlation 8a-a'.

Figures 52 to 56, inclusive, indicate that for any one sand and W/C value, the type of water used in the mortar has little influence upon the value of DYE (dynamic Young's elastic modulus of mortar in the solid state); on the basis of available data, this holds true at any age not greater than one year and probably is true at greater ages.

Correlation 8b-a'.

The possibility of a family of curves, such as shown in Figure 54 relative to distilled water, leads to the belief that if considerably more test data were available perhaps the evidence would point conclusively to the fact that in the case of R-derived coral sand mortars the variation of DYE with age involves a parabolic or hyperbolic function whereas mortars incorporating coral sands derived otherwise may involve purely linear functions. The mortar test data for the case of ideal-graded sands, shown in Table VIII, would be interpretable in this regard had there been companion mortars (of the variously derived sands) available for test at all four ages.

Correlation 8c-a'.

The variation of DYE of mortars (incorporating distilled water) with percent sand voids is illustrated in Figure 57; reference to Table VII shows that the relationship of these two factors at later ages is similar to that at early ages. Insufficient data exist for brackish water (Table VIII). Trends to be expected with mortars containing sea water are detectable from Table IX.

Correlation 8d-a'.

Not evaluated for reasons stated in Section 2.

Correlation 8e-a'.

Figure 58 shows the reduction in DYE that can be expected as the CCS (confined crushing strength) of the sand increases. Unfortunately, only two of the sands signified in the figure are provided for in Table VIII; nevertheless, the comparison of the DYE values for ideal-graded SS and GMRf, at age 28 days and with W/C of 0.5, suggests that comparable mortars incorporating ideal-graded sands probably would reflect the same trends shown in Figure 58.

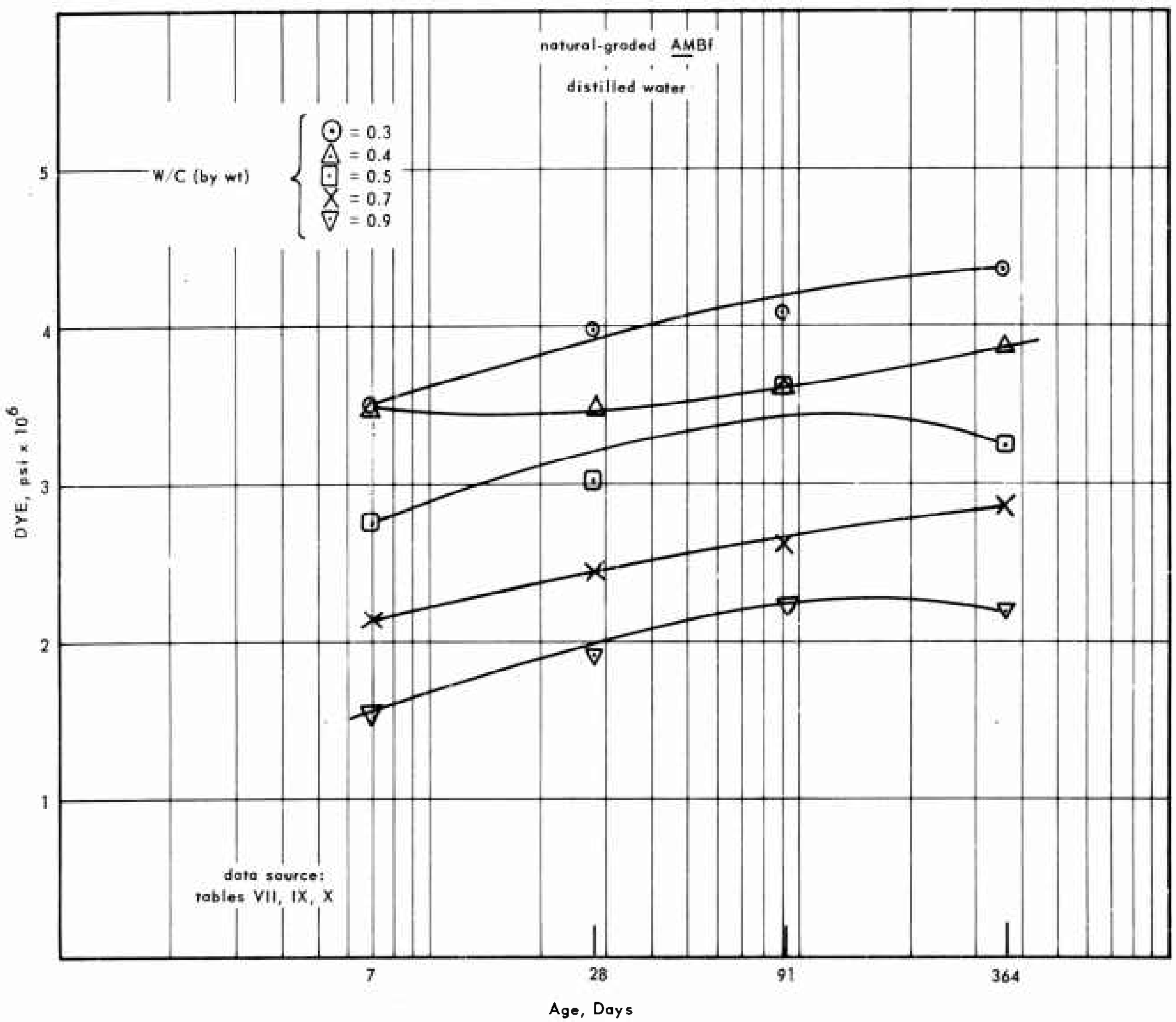

Figure 52. Correlations 8a-a' and 8b-a'. (Part 1 of 3)

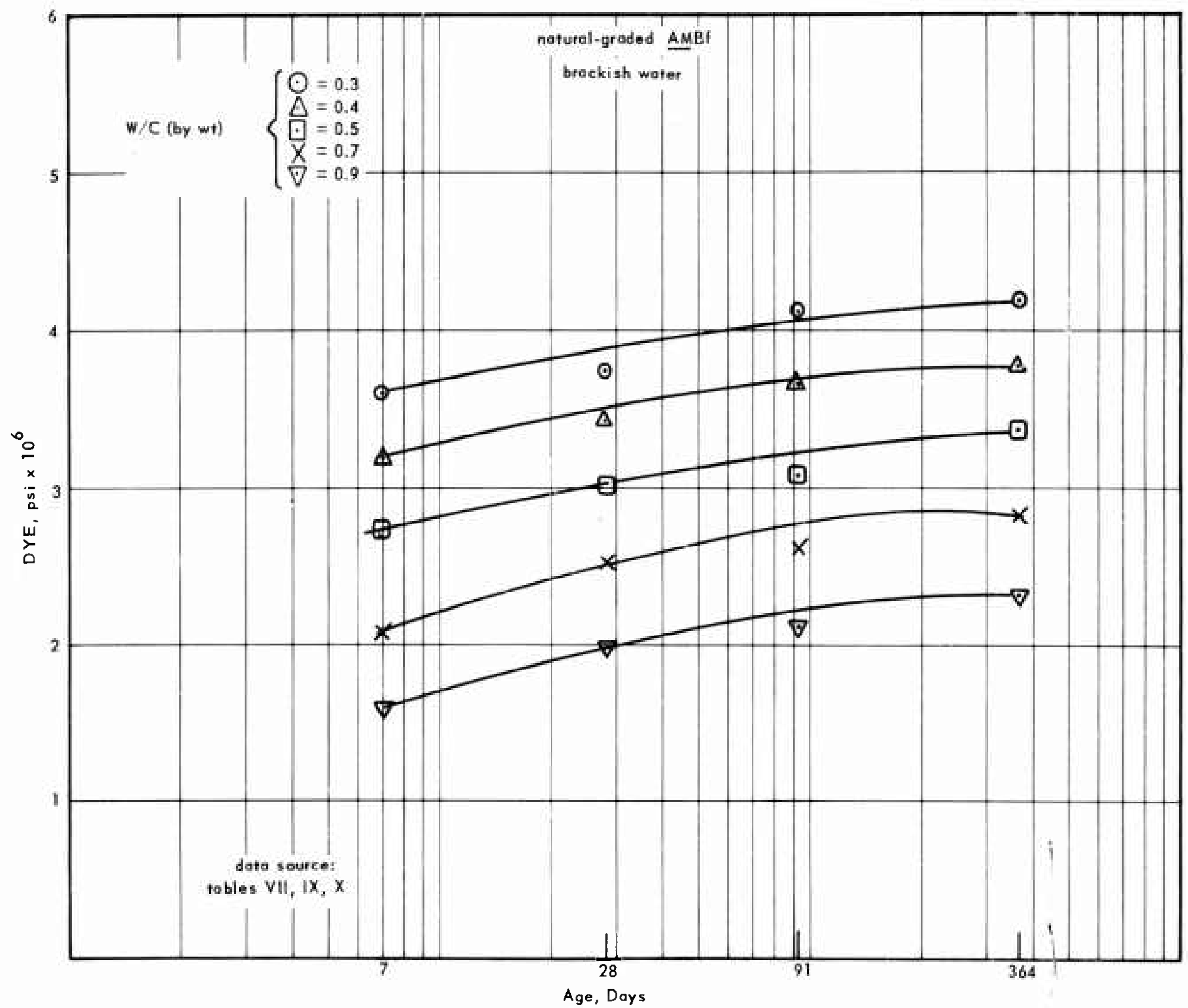

Figure 52. Correlations 8a-a' and 8b-a'. (Part 2 of 3)

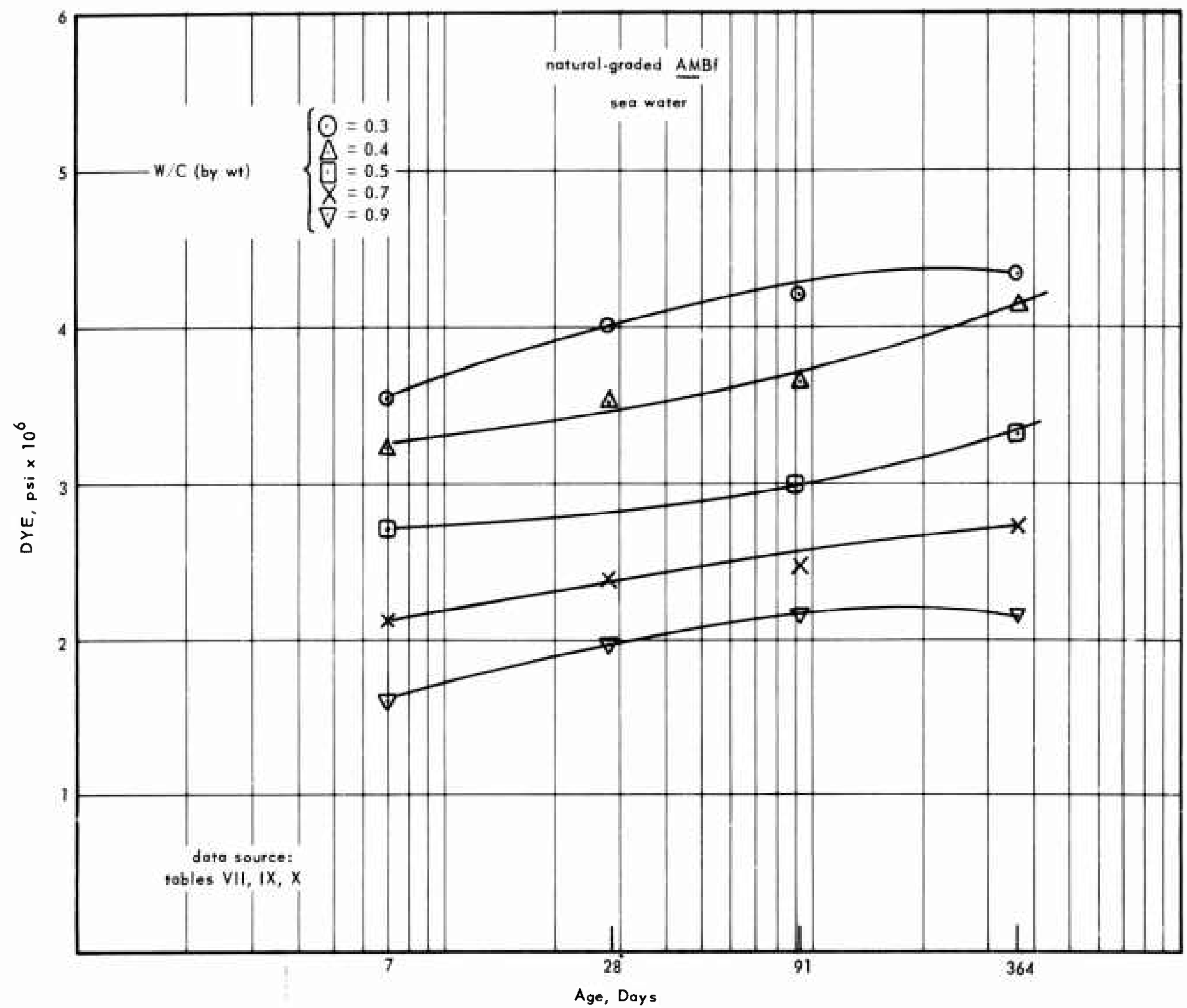

Figure 52. Correlations 8a-a' and 8b-a'. (Part 3 of 3)

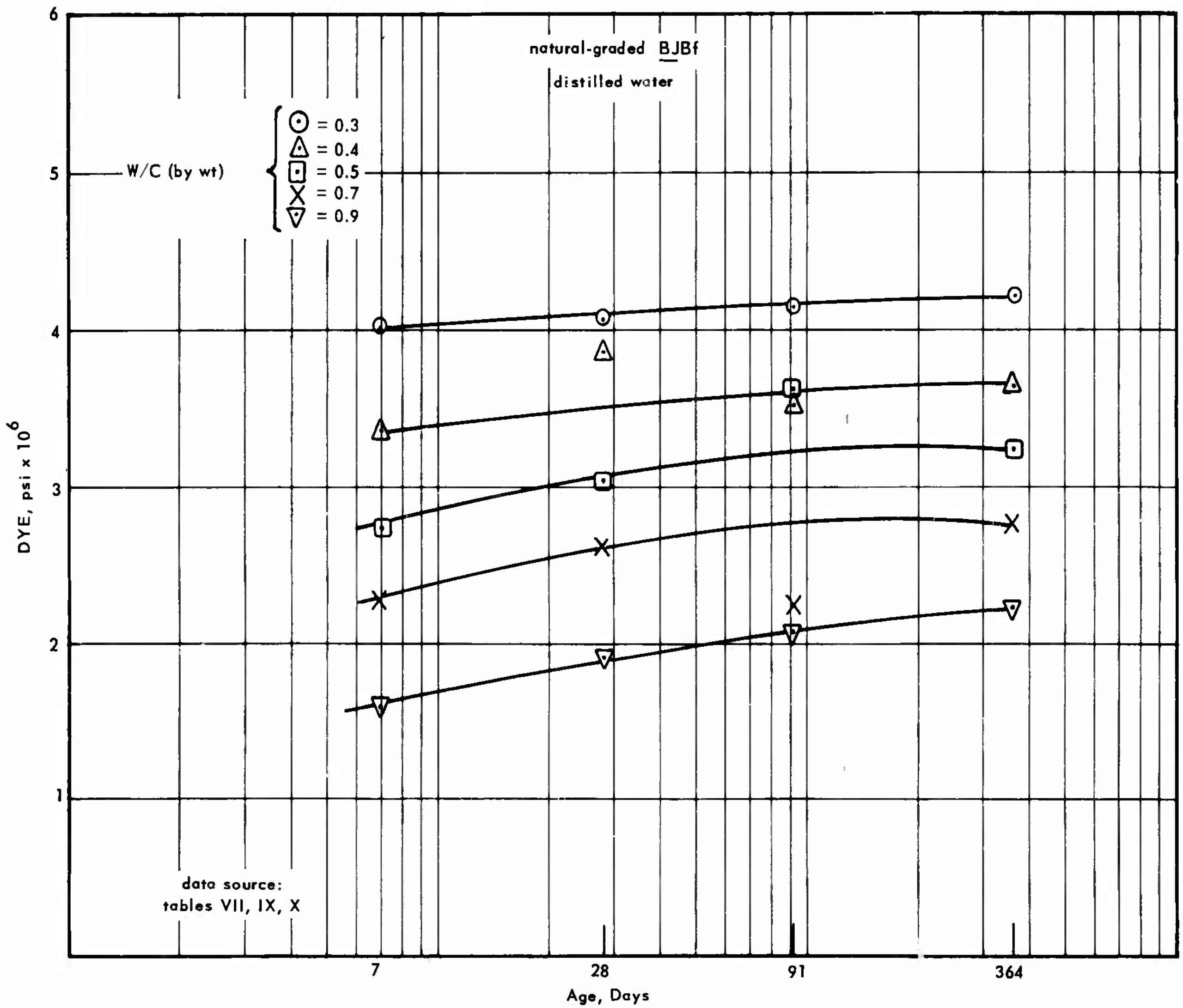

Figure 53. Correlations 8a-a' and 8b-a'. (Part 1 of 3)

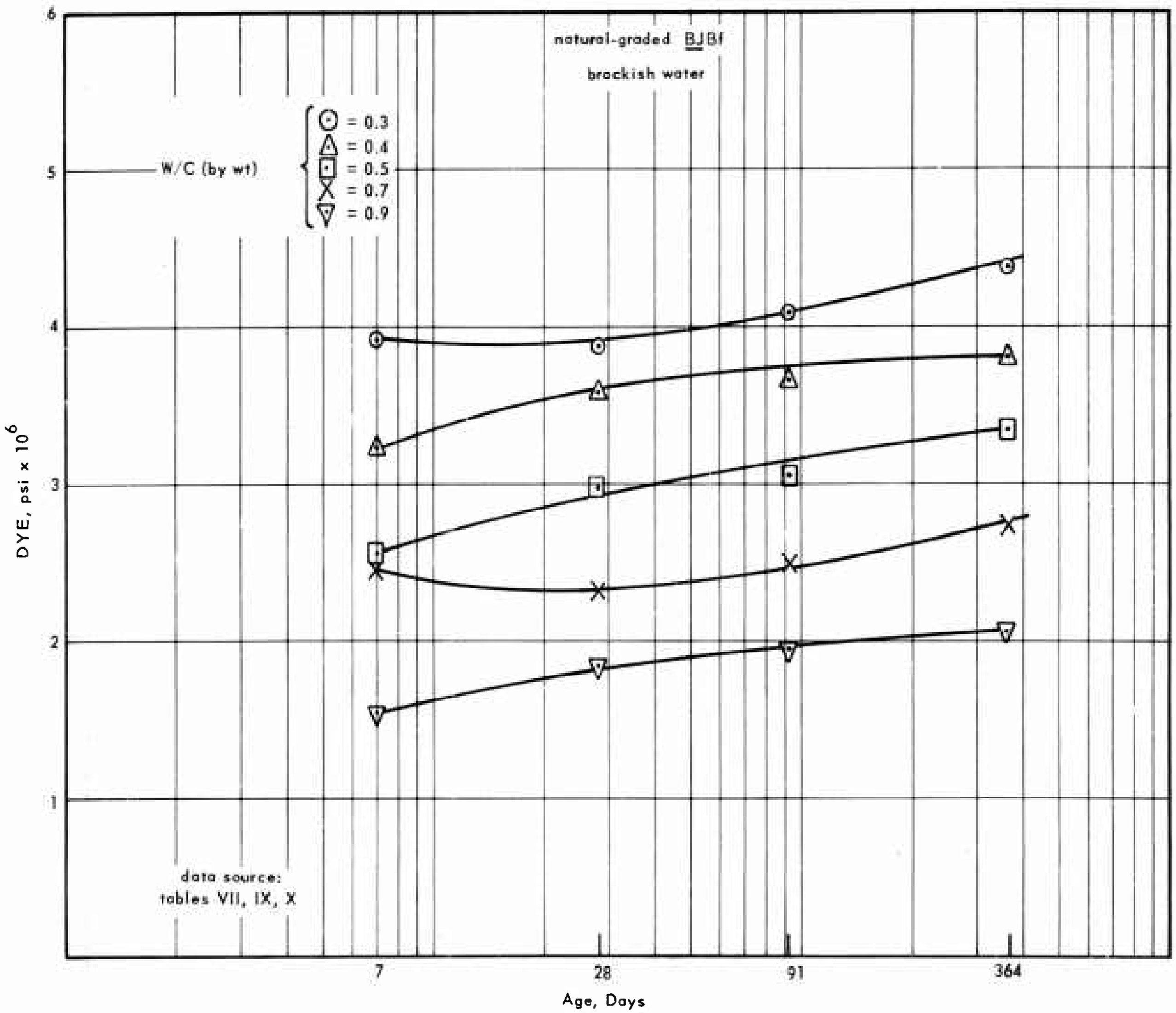

Figure 53. Correlations 8a-a' and 8b-a'. (Part 2 of 3)

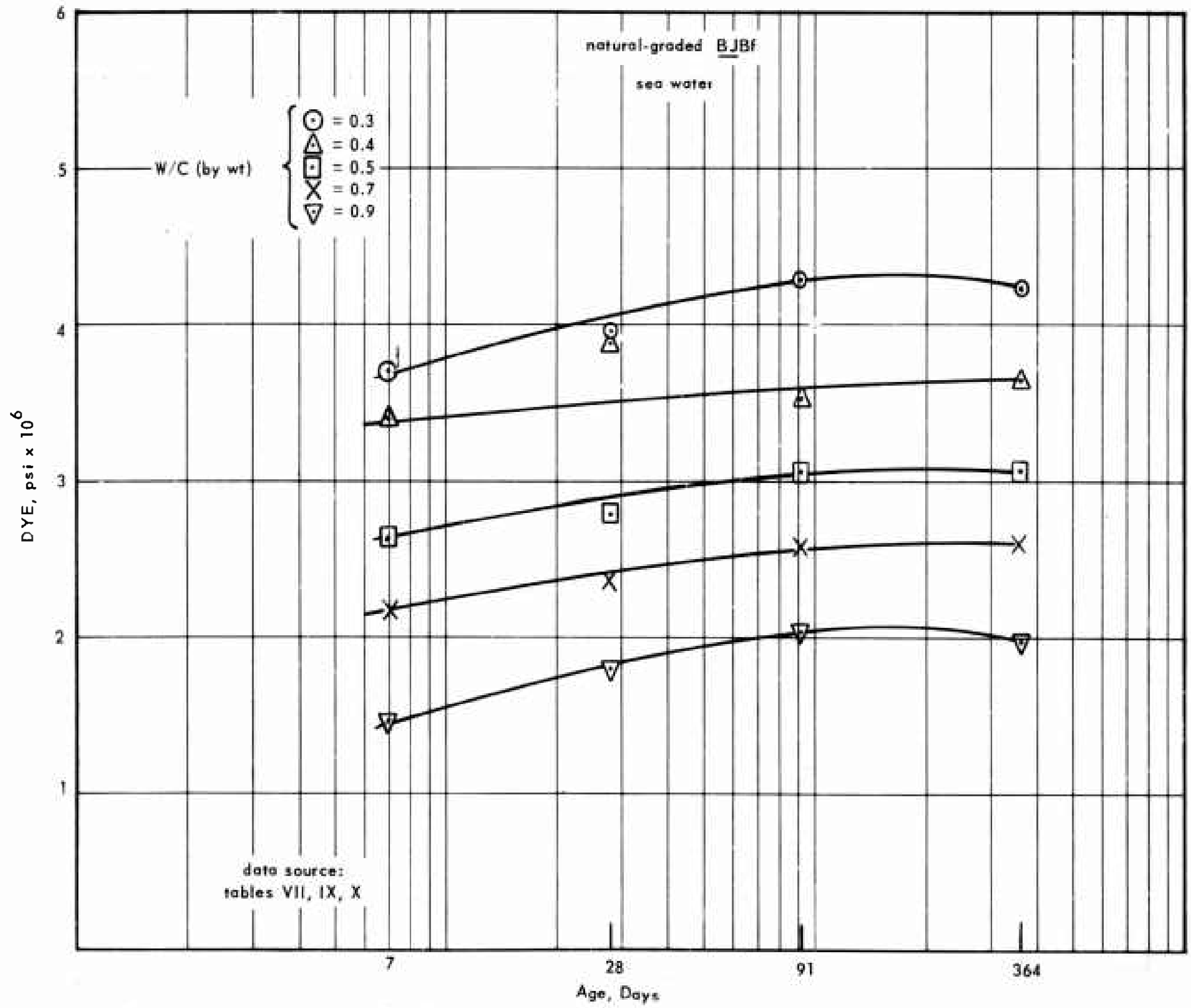

Figure 53. Correlations 8a-a' and 8b-a'. (Part 3 of 3)

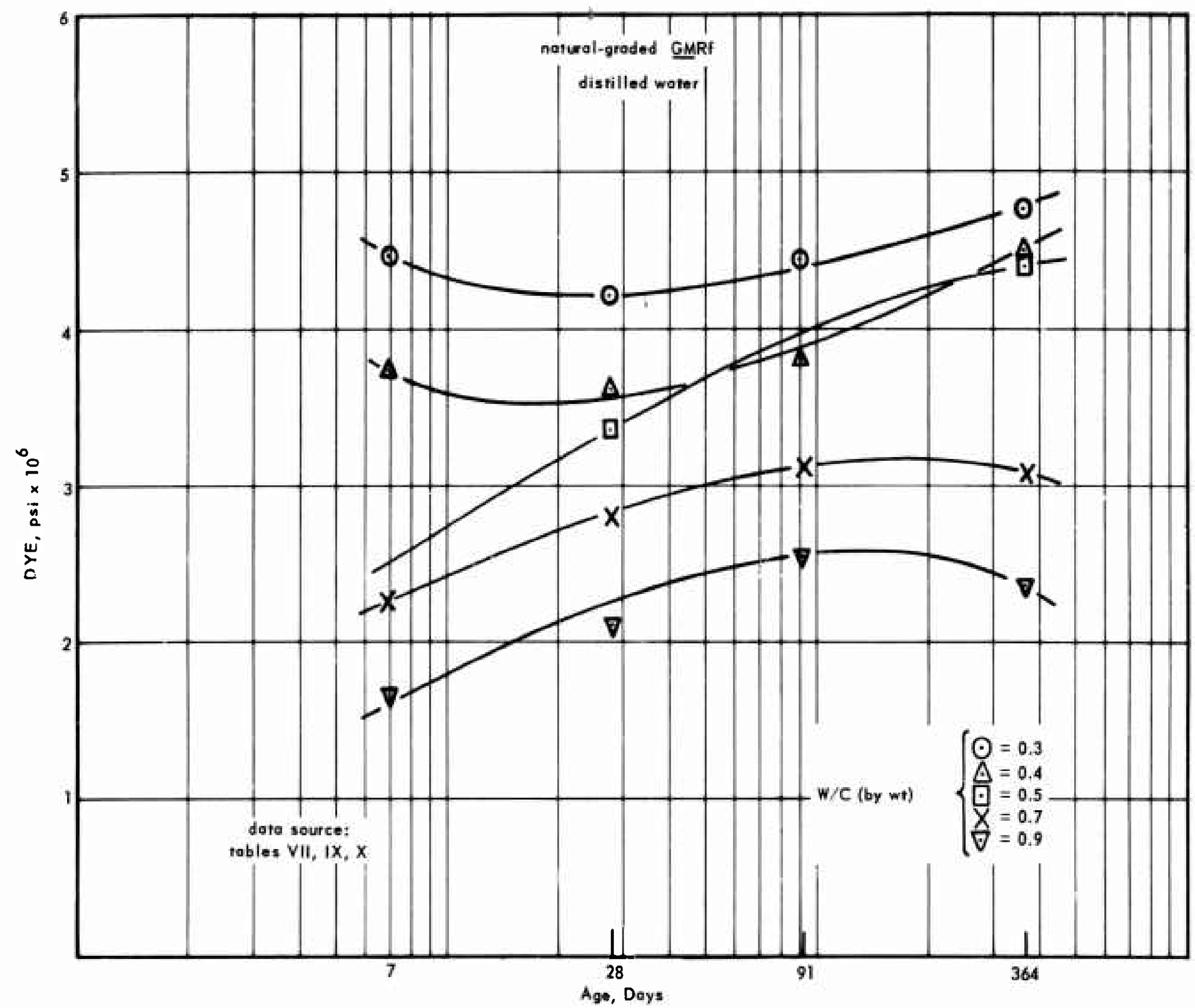

Figure 54. Correlations 8a-a' and 8b-a'. (Part 1 of 3)

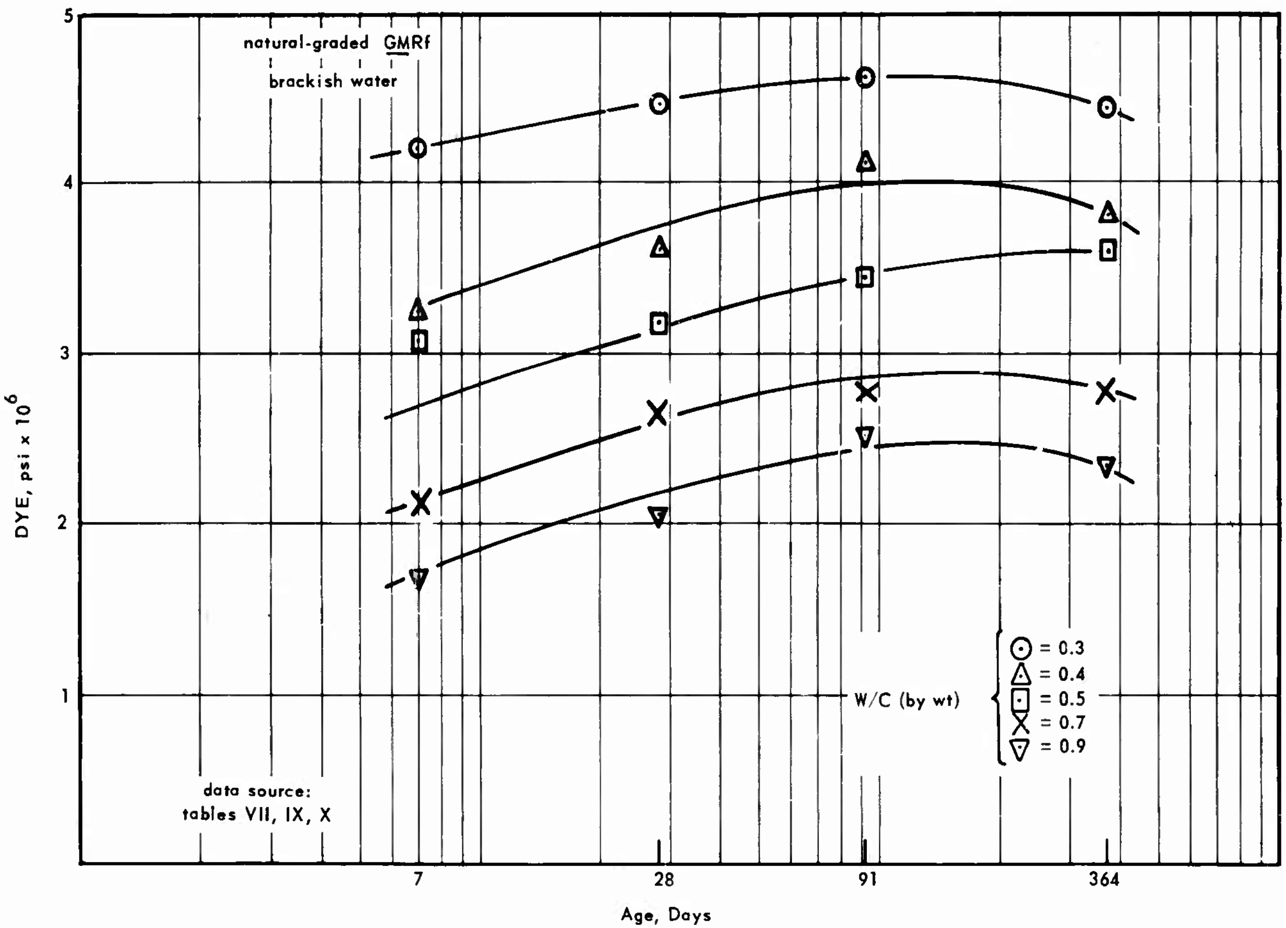

Figure 54. Correlations 8a-a' and 8b-a'. (Part 2 of 3)

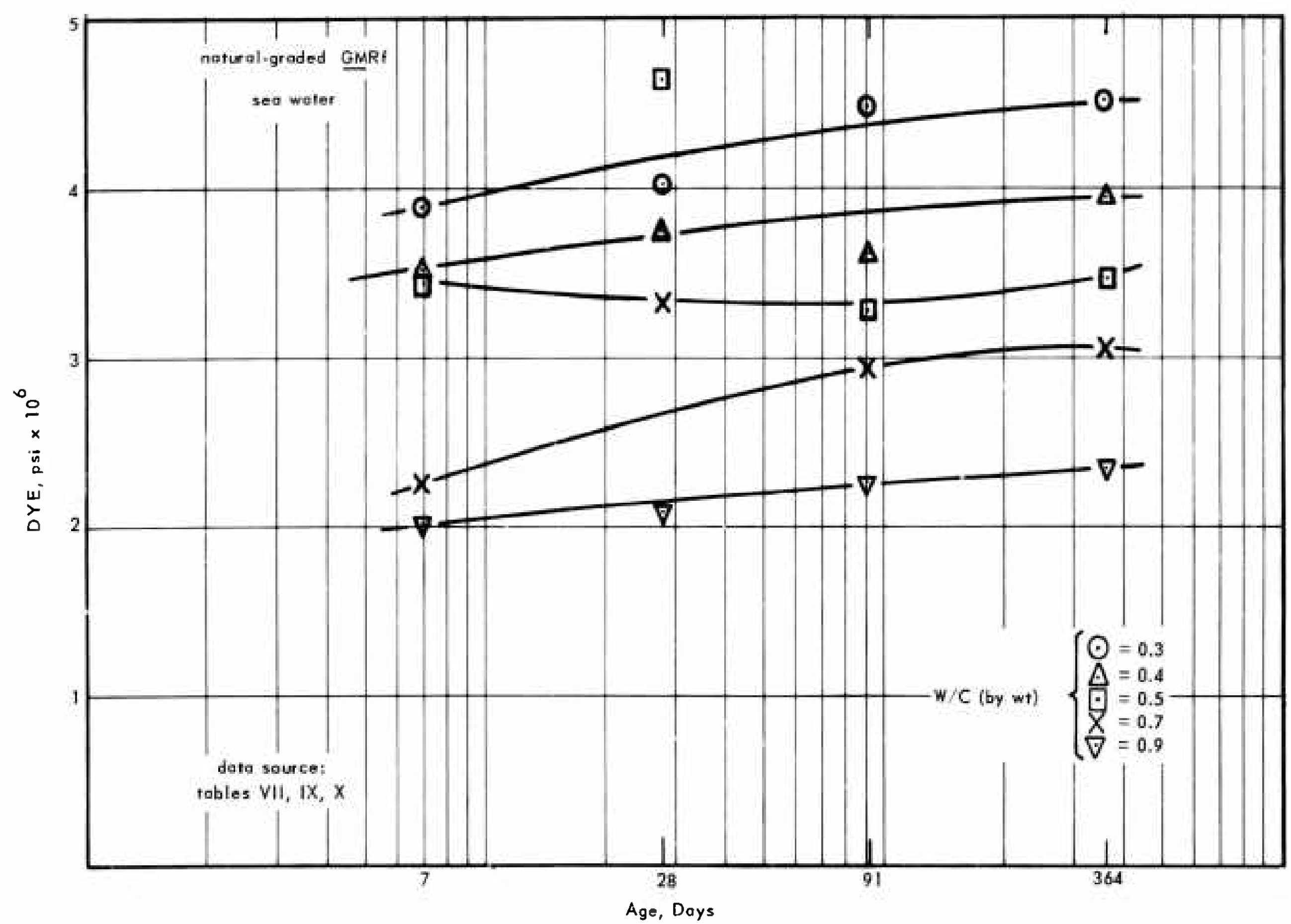

Figure 54. Correlations 8a-a' and 8b-a'. (Part 3 of 3)

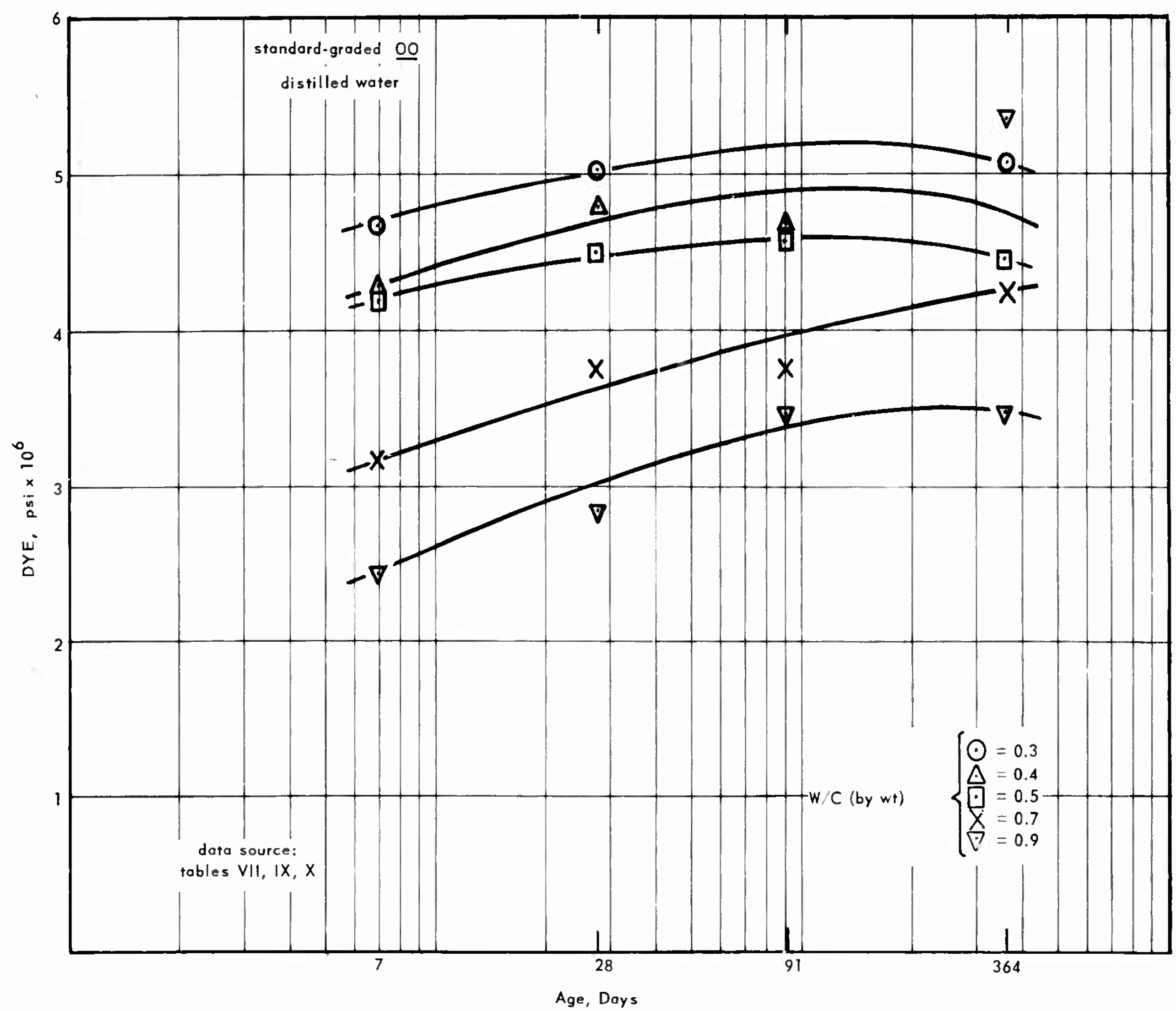

Figure 55. Correlations 8a-a' and 8b-a'. (Part 1 of 3)

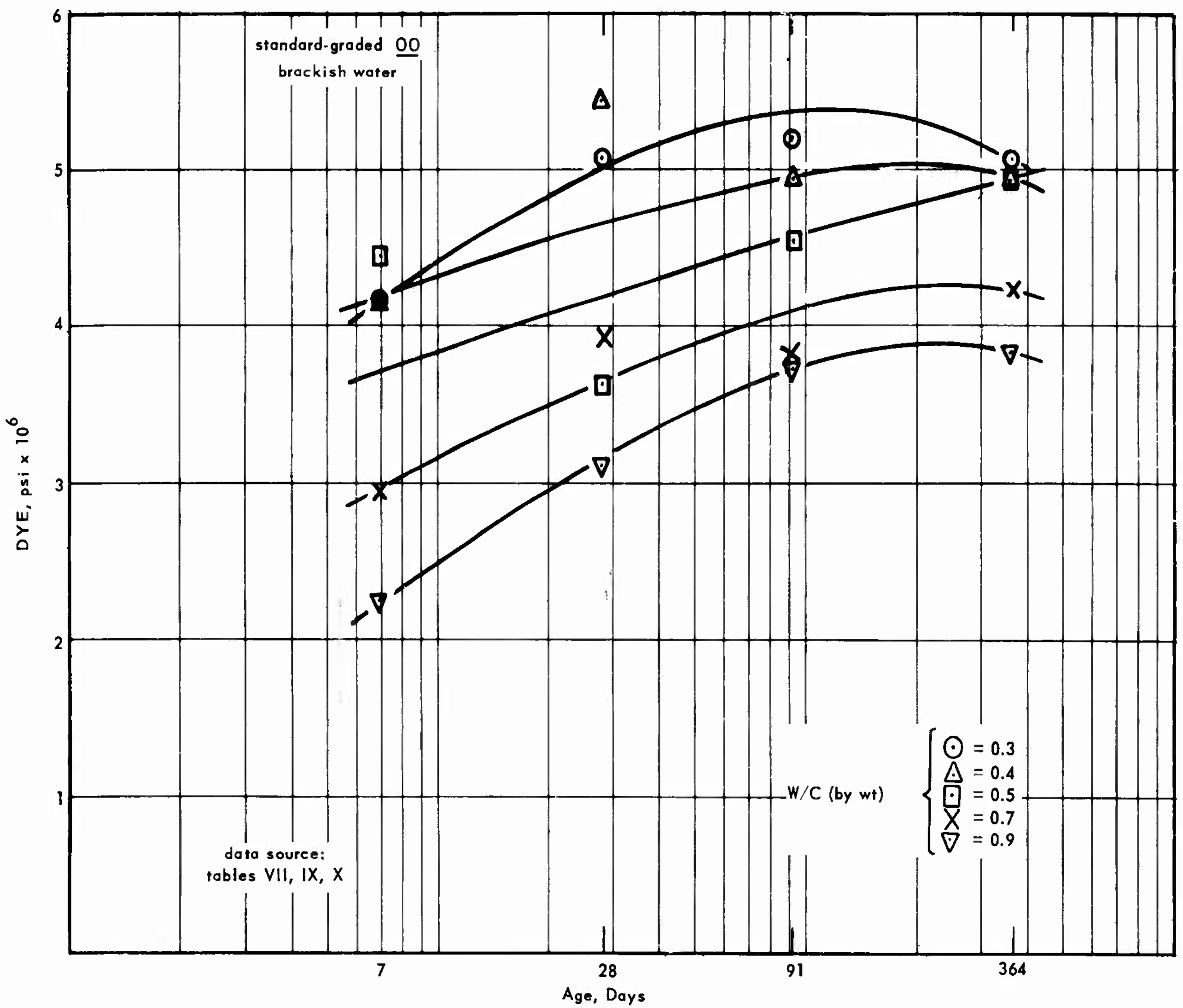

Figure 55. Correlations 8a-a' and 8b-a'. (Part 2 of 3)

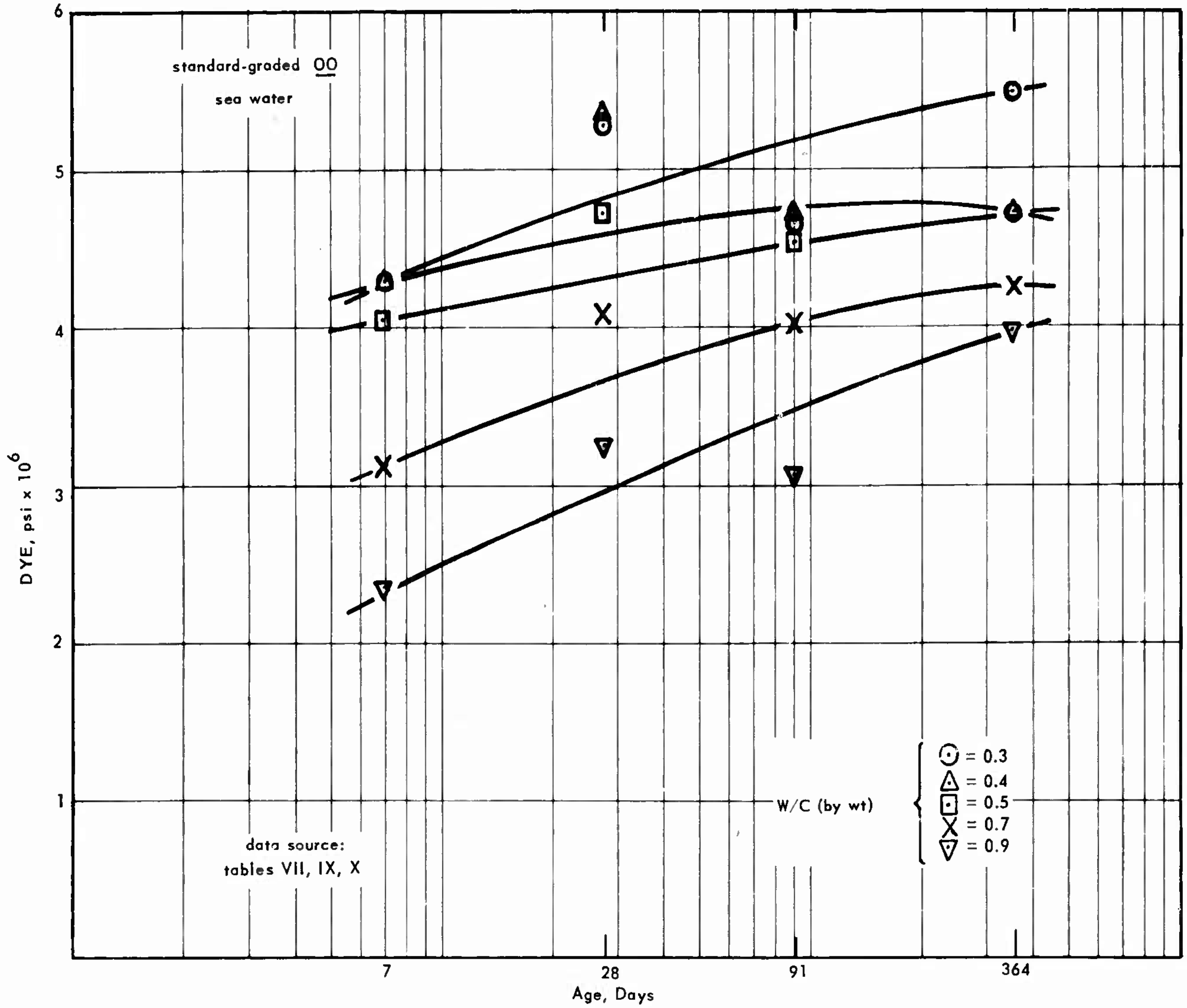

Figure 55. Correlations 8a-a' and 8b-a'. (Part 3 of 3)

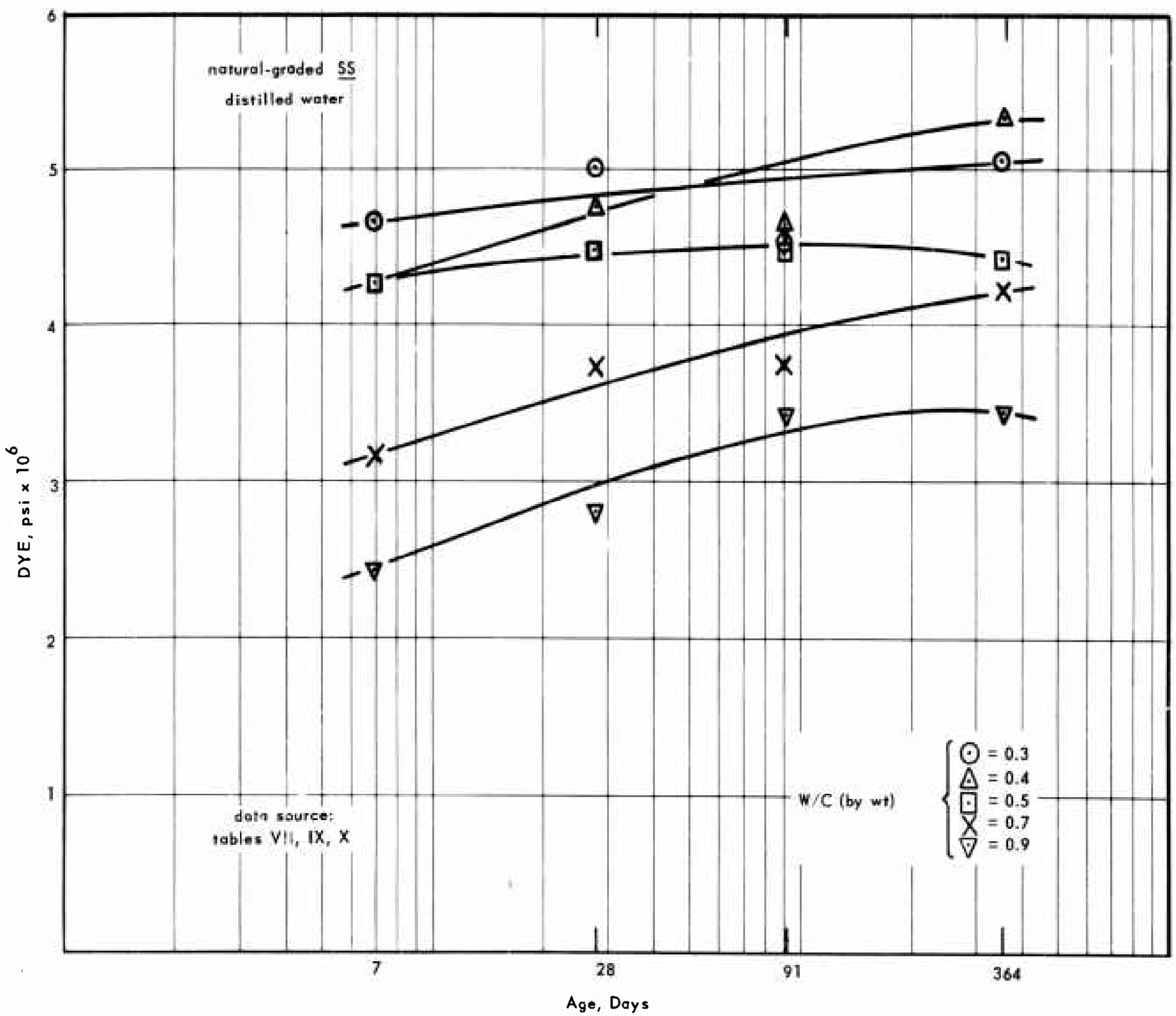

Figure 56. Correlations 8a-a' and 8b-a'. (Part 1 of 3)

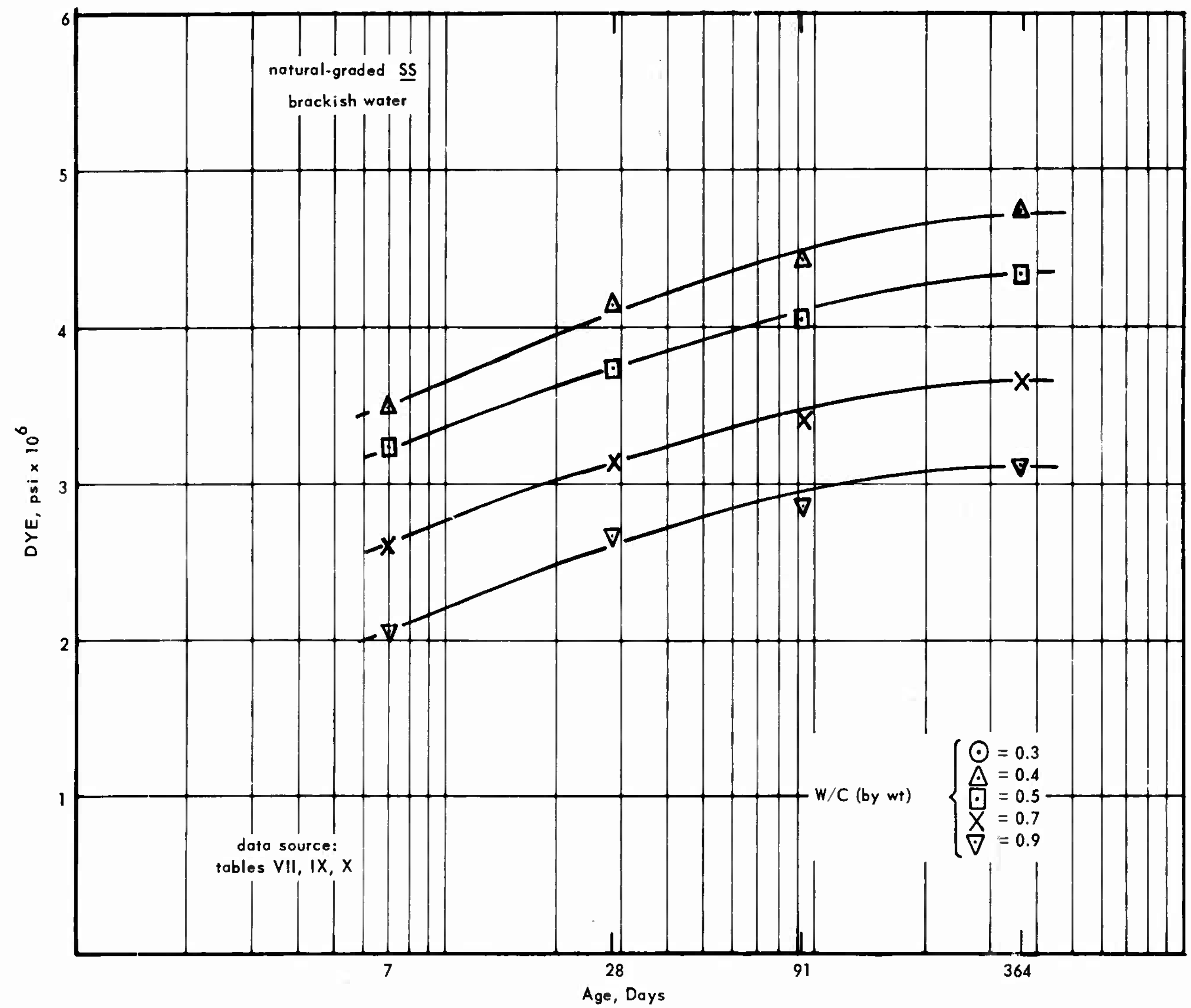

Figure 56. Correlations 8a-a' and 8b-a'. (Part 2 of 3)

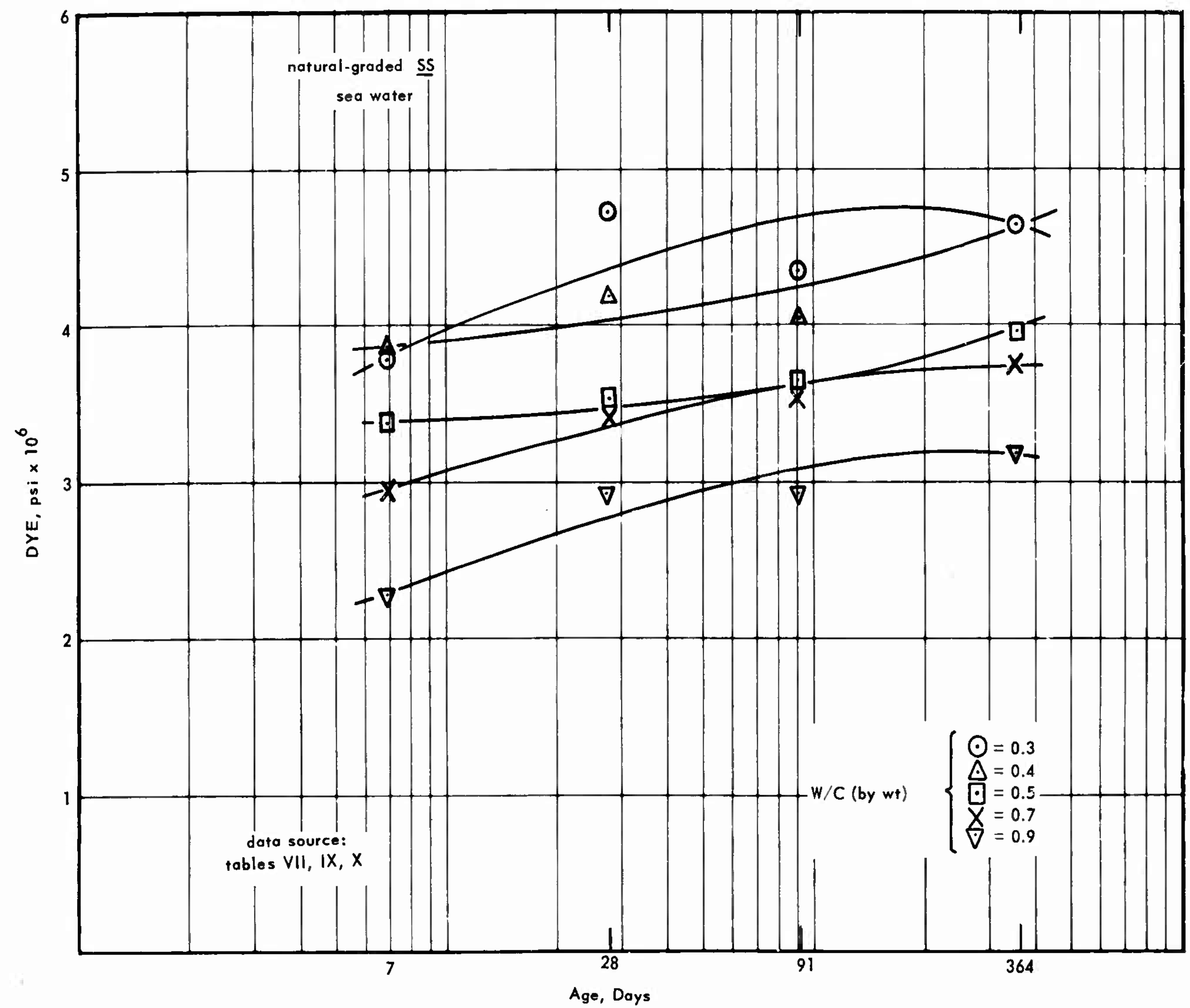

Figure 56. Correlations 8a-a' and 8b-a'. (Part 3 of 3)

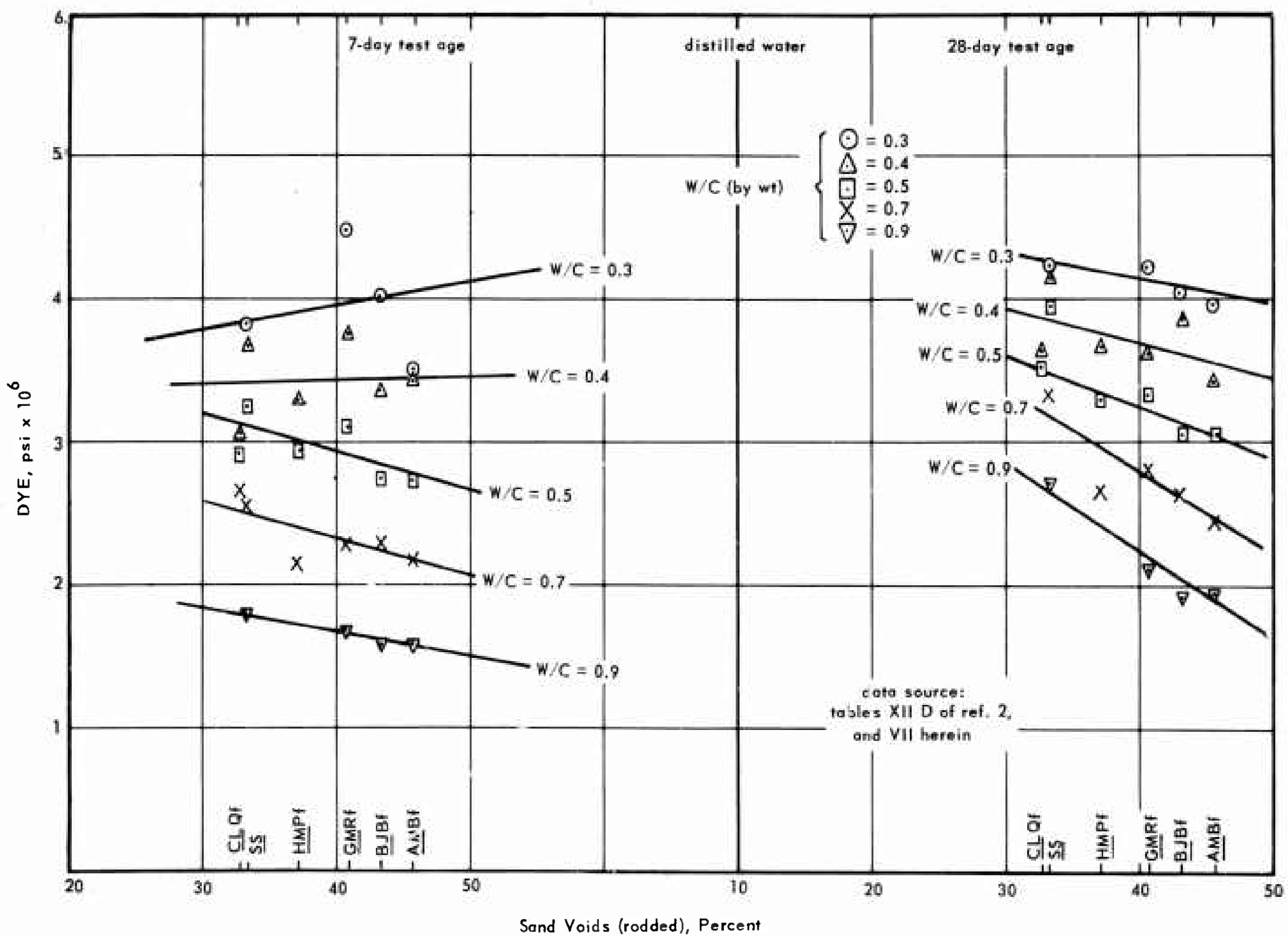

Figure 57. Correlation 8c-a'.

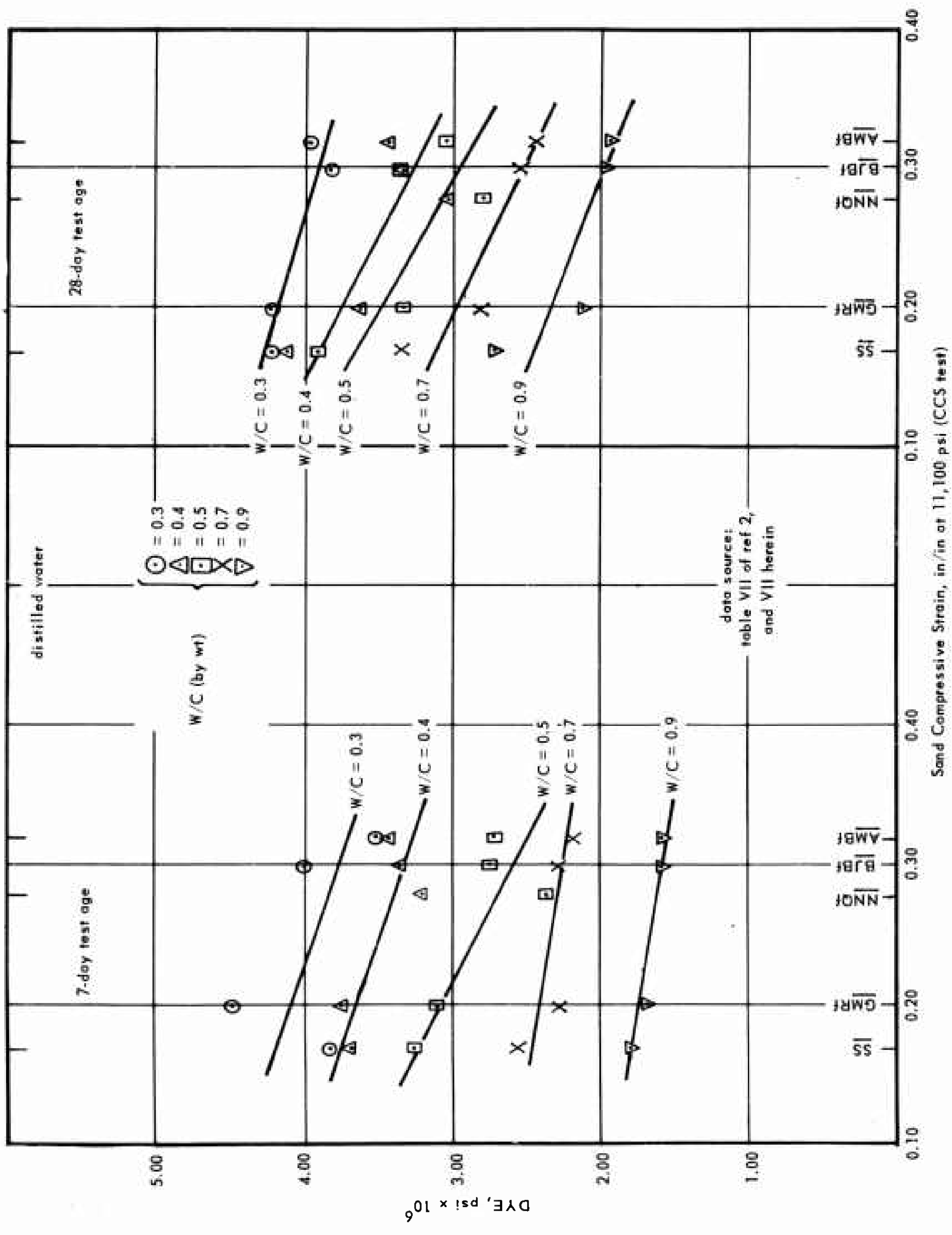

Figure 58. Correlation 8e-σ'.

Correlation 8f-a'.

Not evaluated for reasons stated in Section 2.

Correlation 8g-a'.

Figures 59 to 61, inclusive, show more effectively than Tables VII, VIII, and IX that at any age to one year, regardless of water type and regardless of whether coral sand is R- or B-derived, the DYE of coral mortars ranges generally from 2 to 4 million psi, whereas for companion reference mortars the range is from 3 to 5 million psi, with OO mortars always exhibiting the highest values of DYE for any W/C value.

Correlation 8h-a'.

An illustration of the typical DYE relationship among mortars fabricated with variously derived coral sands and reference sands, and the influence of A/C values upon DYE of such typical mortars, is given in Figure 62. Curves relative to other ages and other W/C values, using ideal-graded materials with distilled water or using natural-graded materials with brackish or sea water, can be established in similar fashion from the data in Tables VII to X, inclusive. Such additional curves would differ from those in Figure 61 to no greater degree than the curves (Figure 63) typified for mortars incorporating R-derived coral sands.

Correlation 8i-a'.

No consistent variation of DYE values with change in percent flow can be detected from the data available. Figure 64 depicts such relationship for all mortars at age 28 days, using three types of water and three values of W/C. Assuming that the curves (loci of which are based upon medians of various points related to reference-sand and coral-sand mortars) are valid, it appears reasonable to hypothesize that at low W/C values increasing the flow tends to increase the DYE except when sea water is incorporated, in which event increasing the flow tends to decrease the DYE characteristics. This hypothesis is not in conflict with the statements offered in Correlation 8a-a'.

Correlation 8j-a'.

The effect of increasing EAC upon DYE characteristics of the mortars, irrespective of coral sand or reference sand derivations, is exemplified in Figure 65. There is no doubt that the influence of EAC is interwoven with

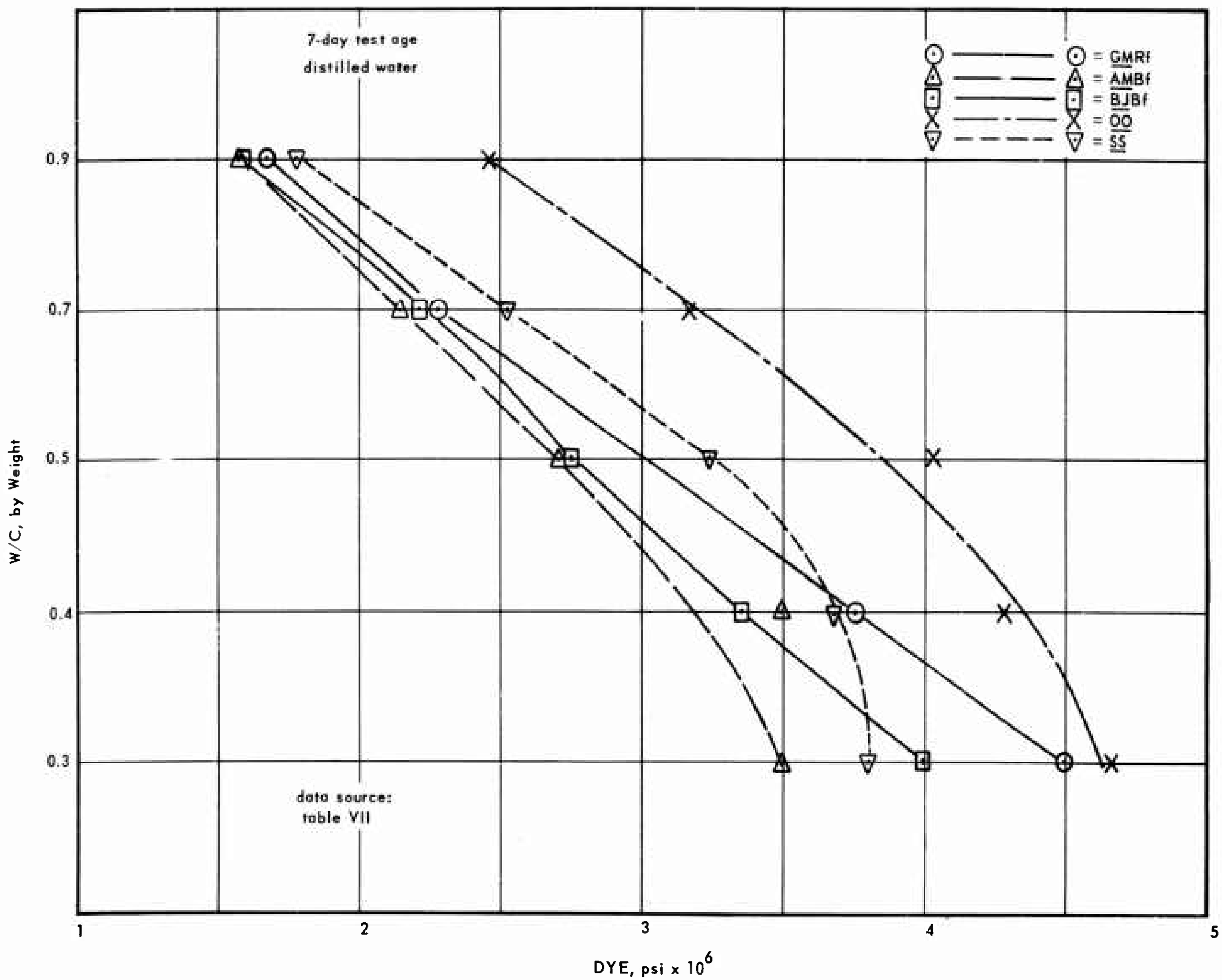

Figure 59. Correlation 8g-a'. (Part 1 of 4)

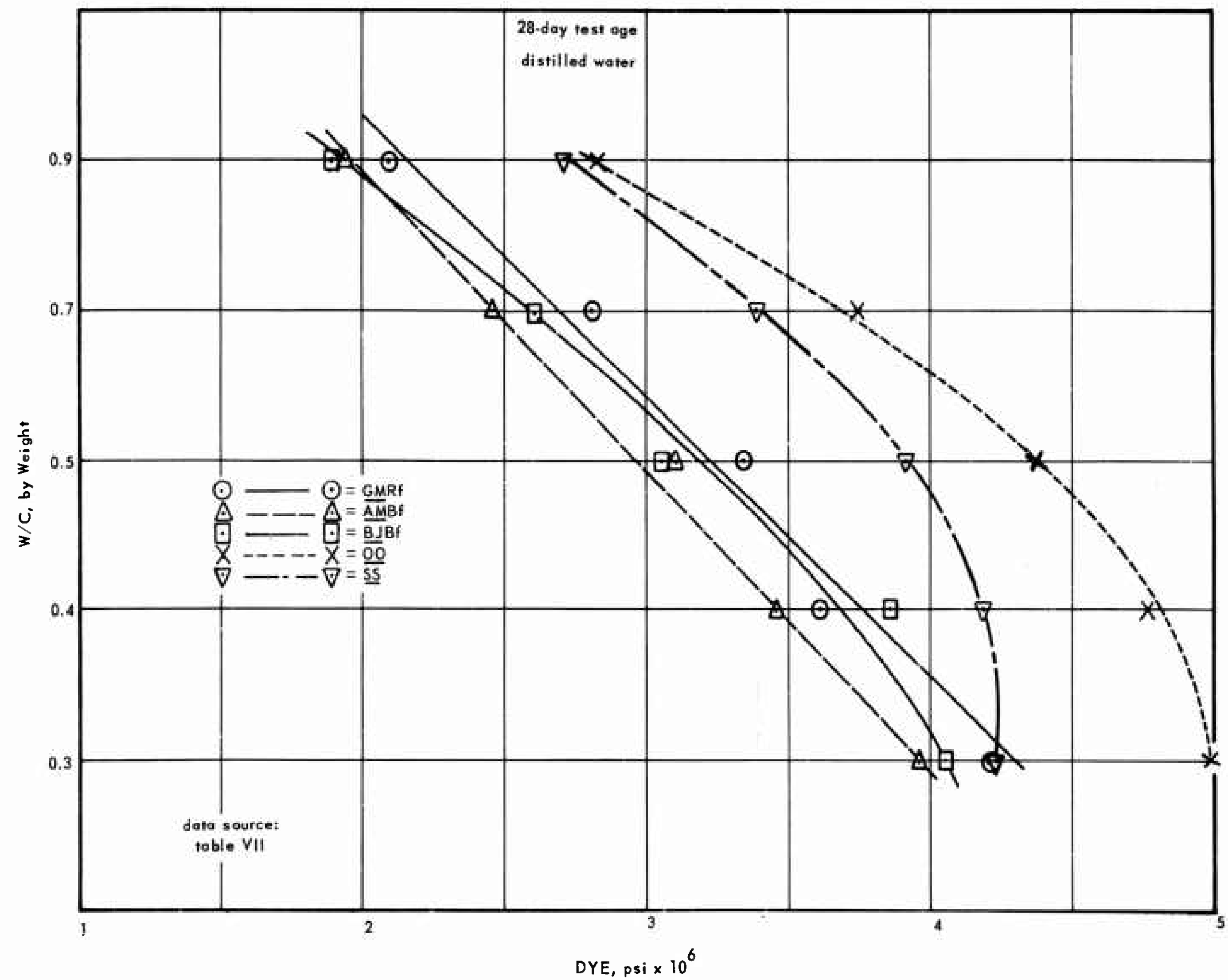

Figure 59. Correlation 8g-a'. (Part 2 of 4)

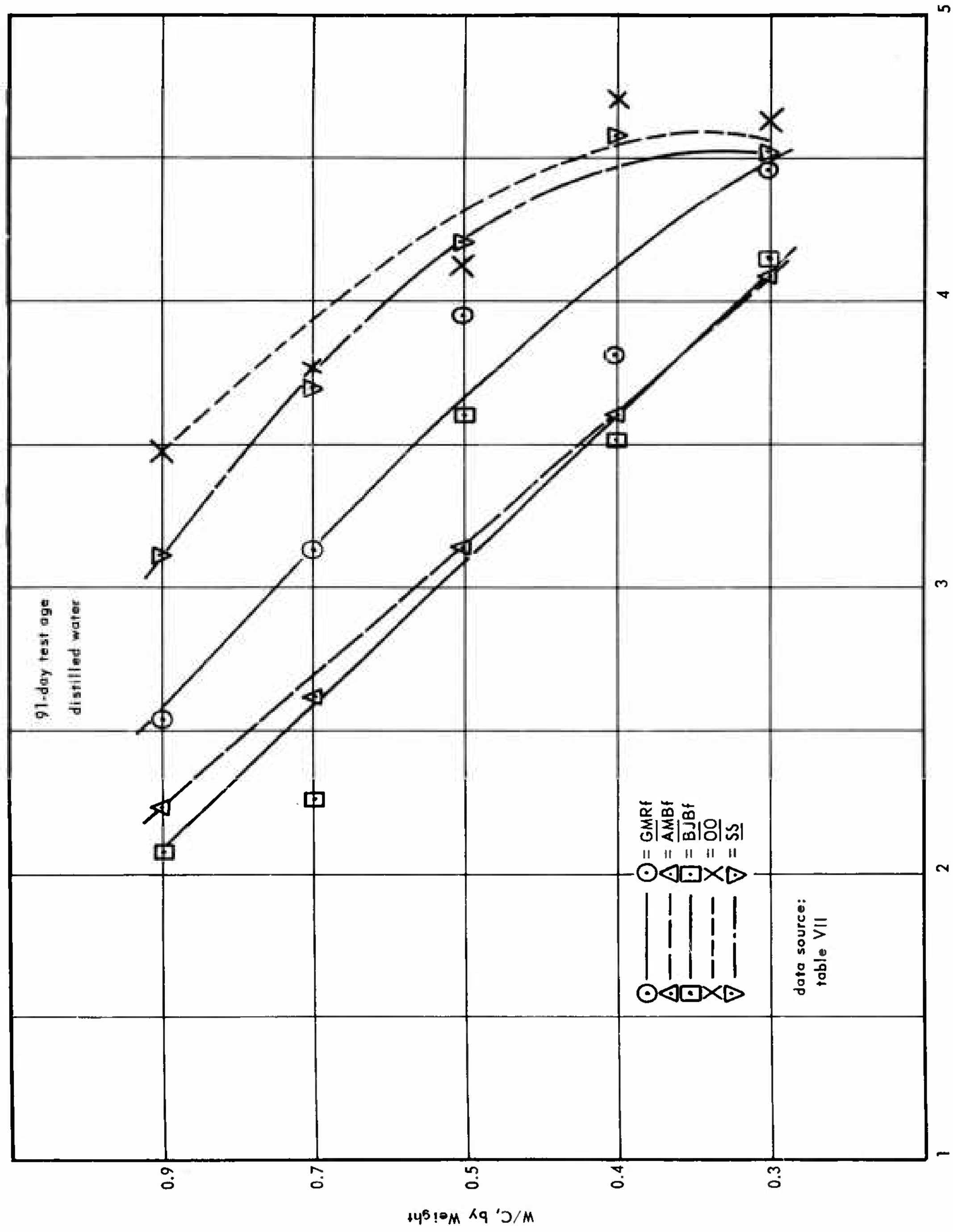

Figure 59. Correlation 8g-a'. (Part 3 of 4)

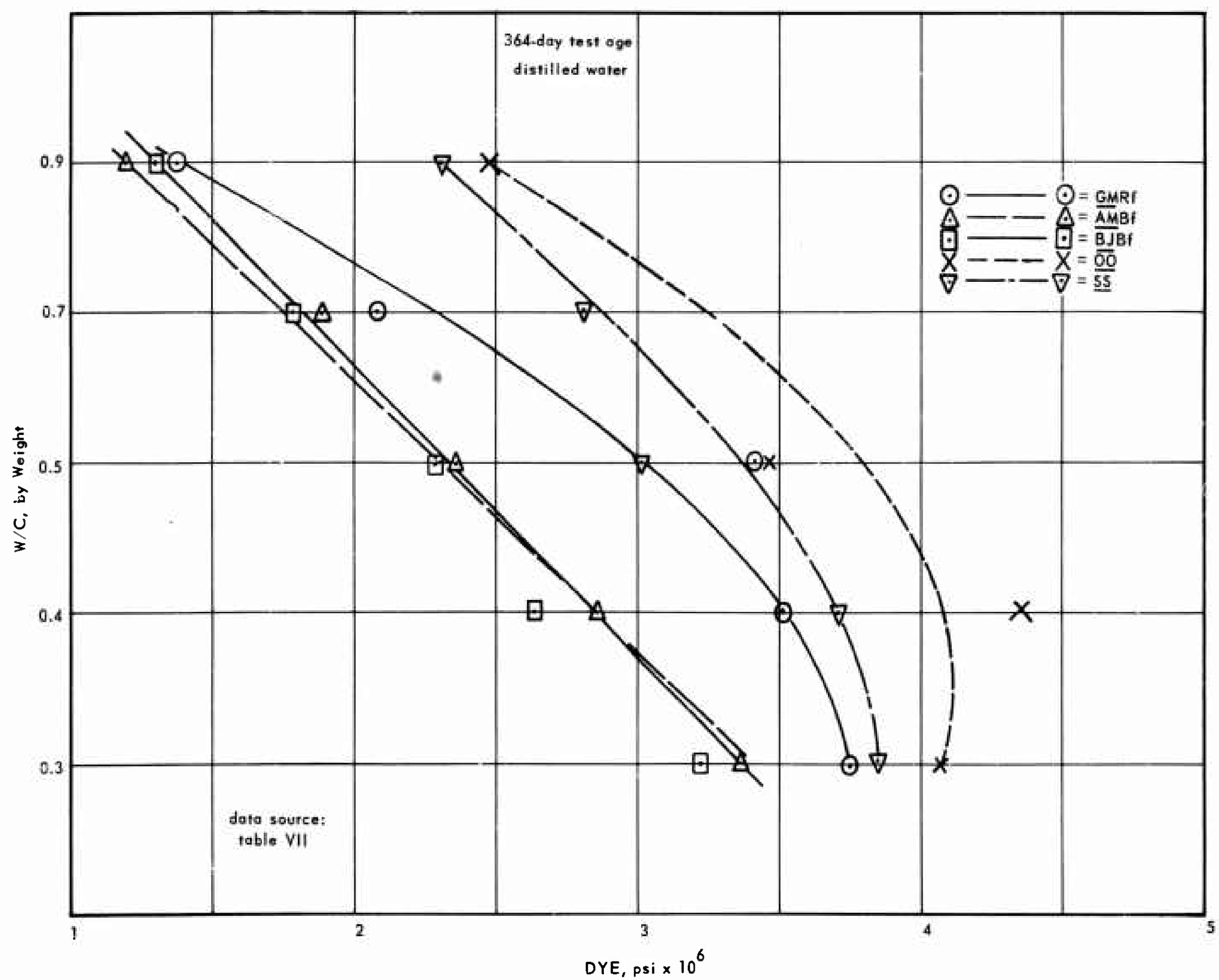

Figure 59. Correlation 8g-a'. (Part 4 of 4)

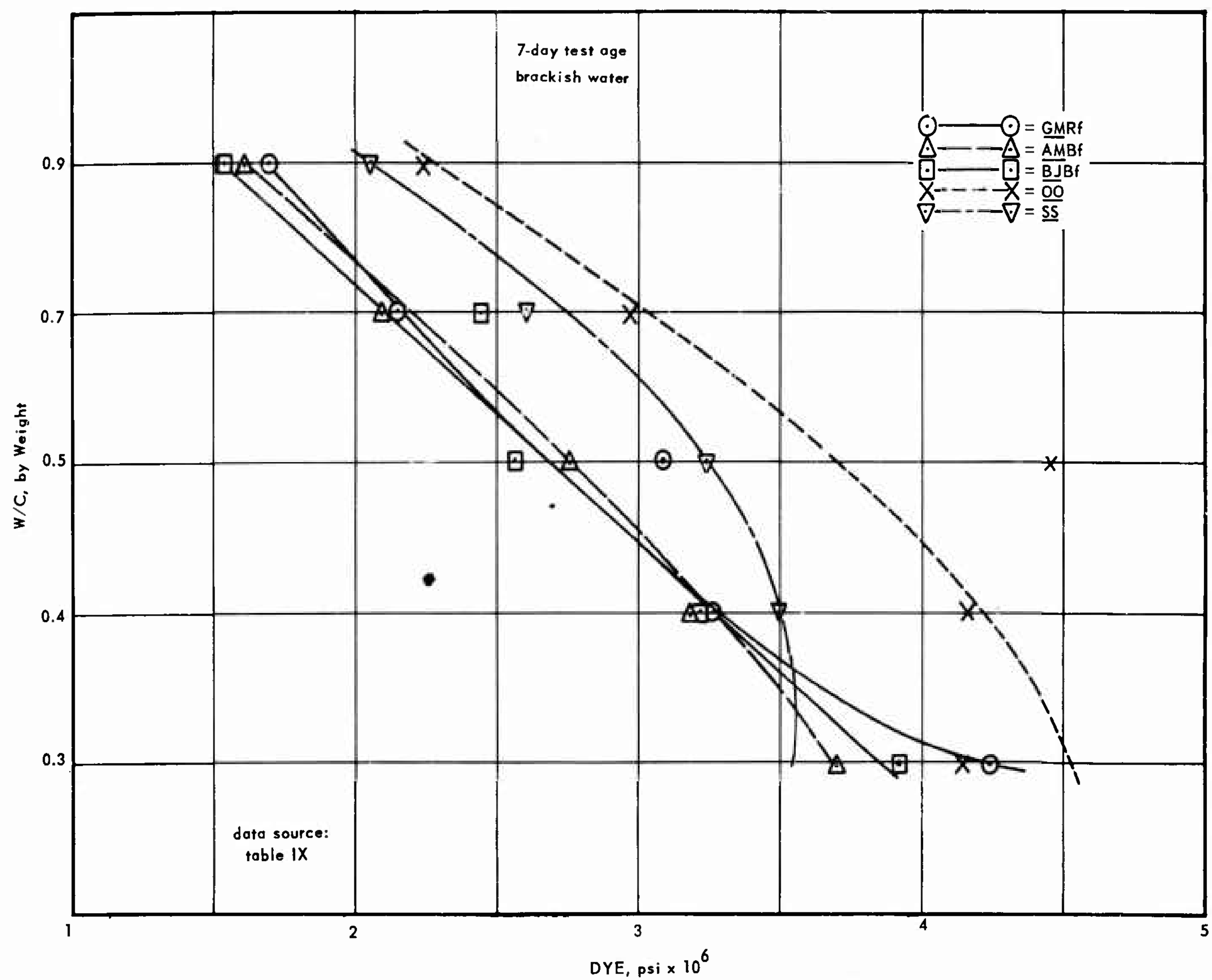

Figure 60. Correlation 8g-a'. (Part 1 of 4)

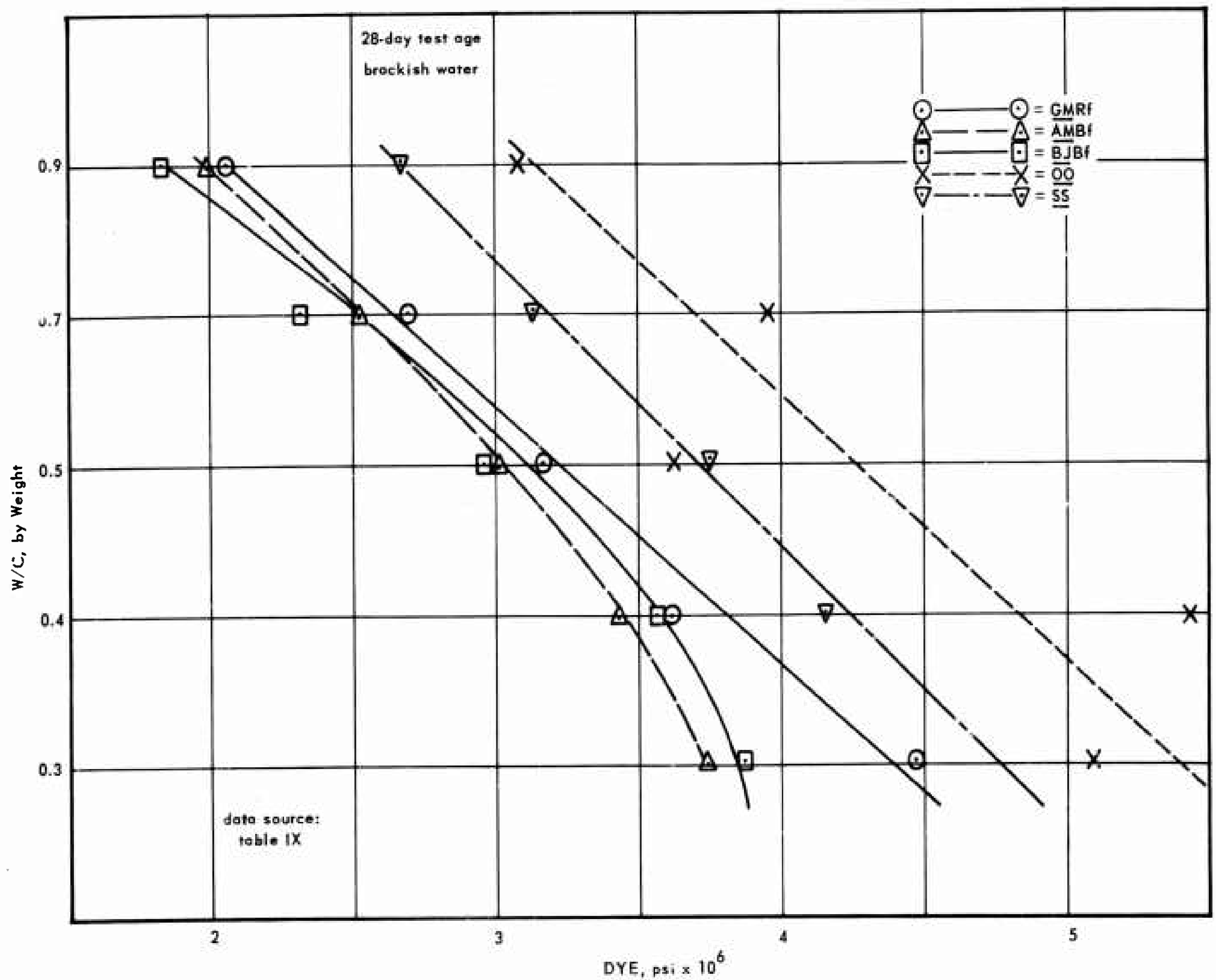

Figure 60. Correlation 8g-a'. (Part 2 of 4)

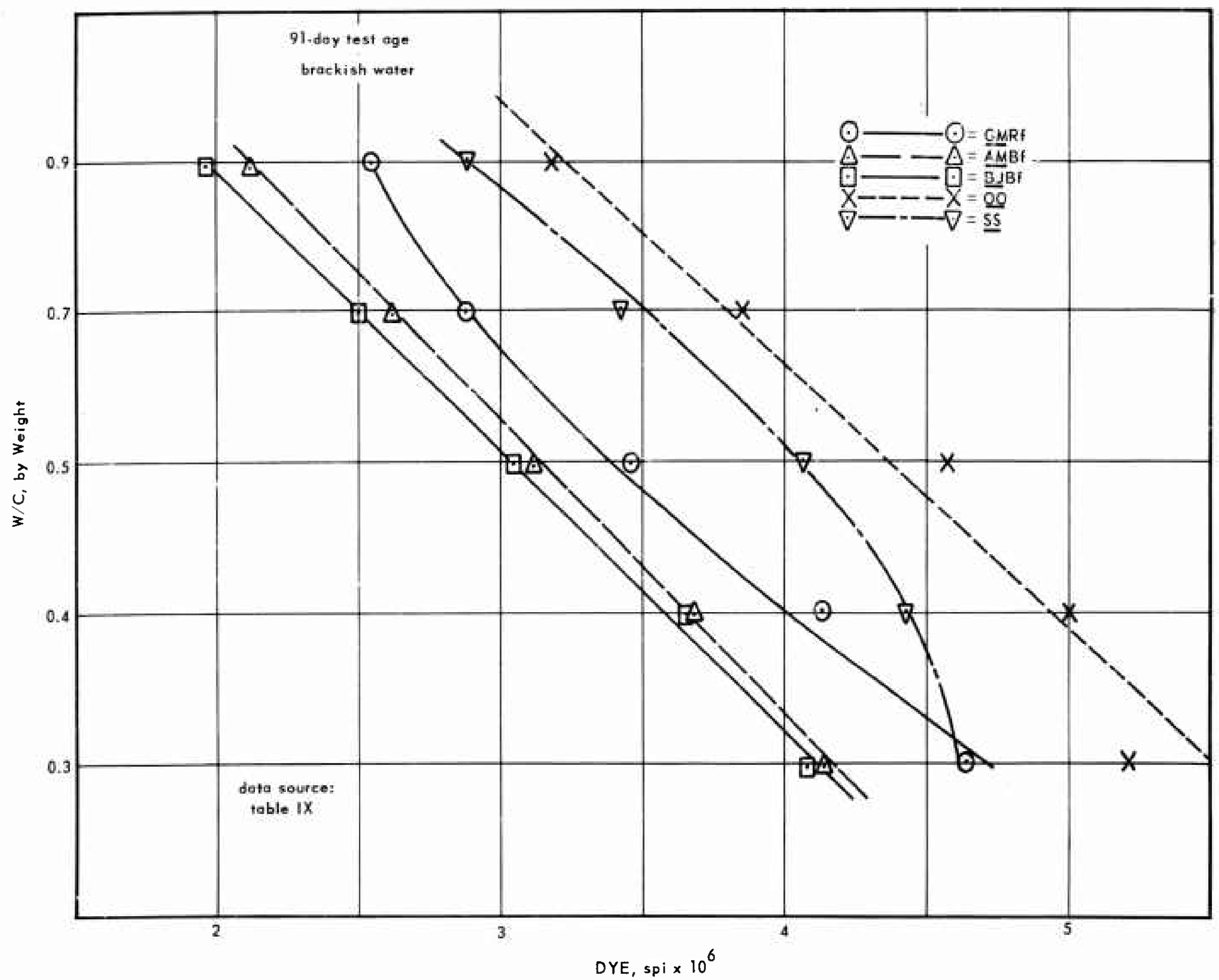

Figure 60. Correlation 8g-a'. (Part 3 of 4)

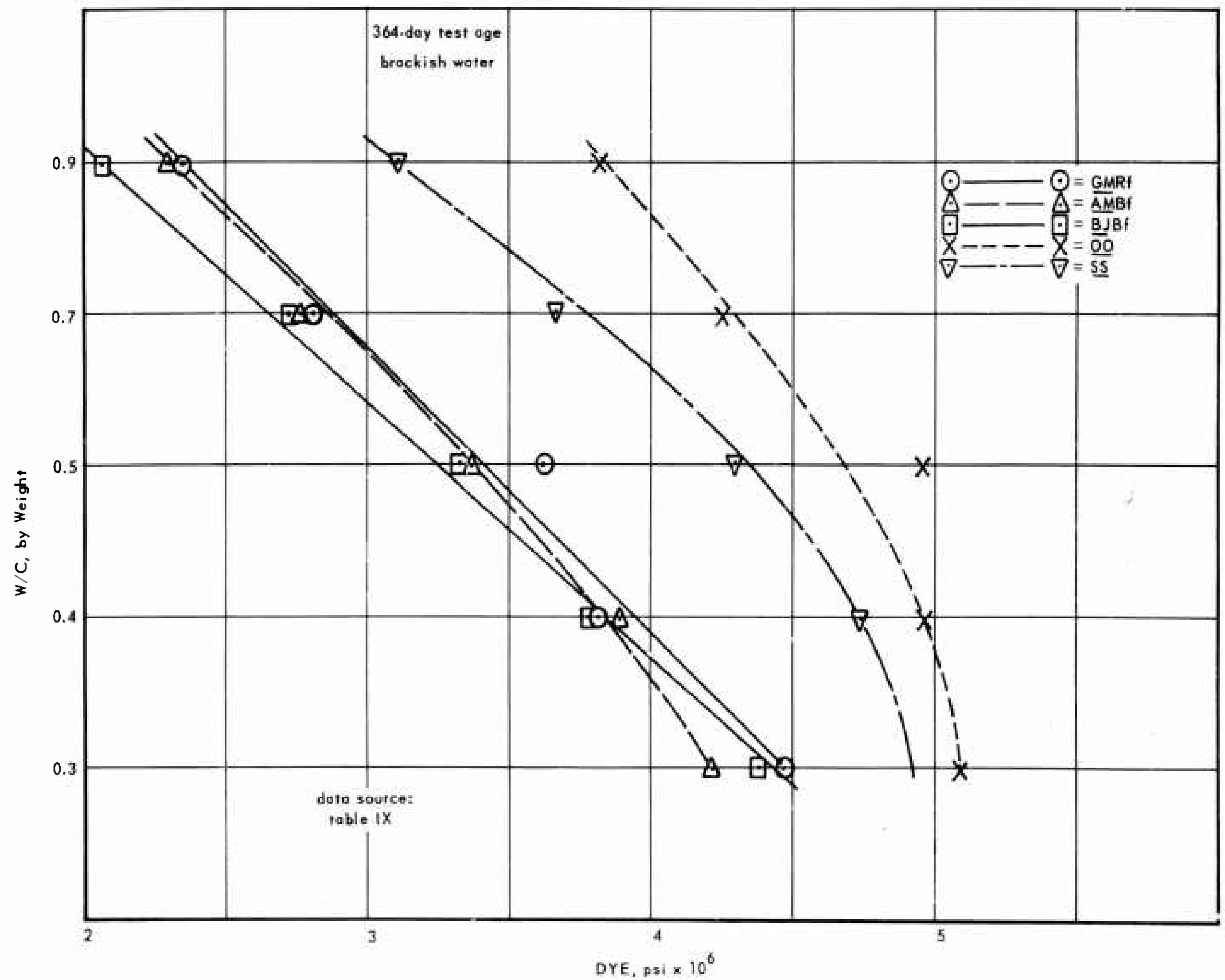

Figure 60. Correlation 8g-a'. (Part 4 of 4)

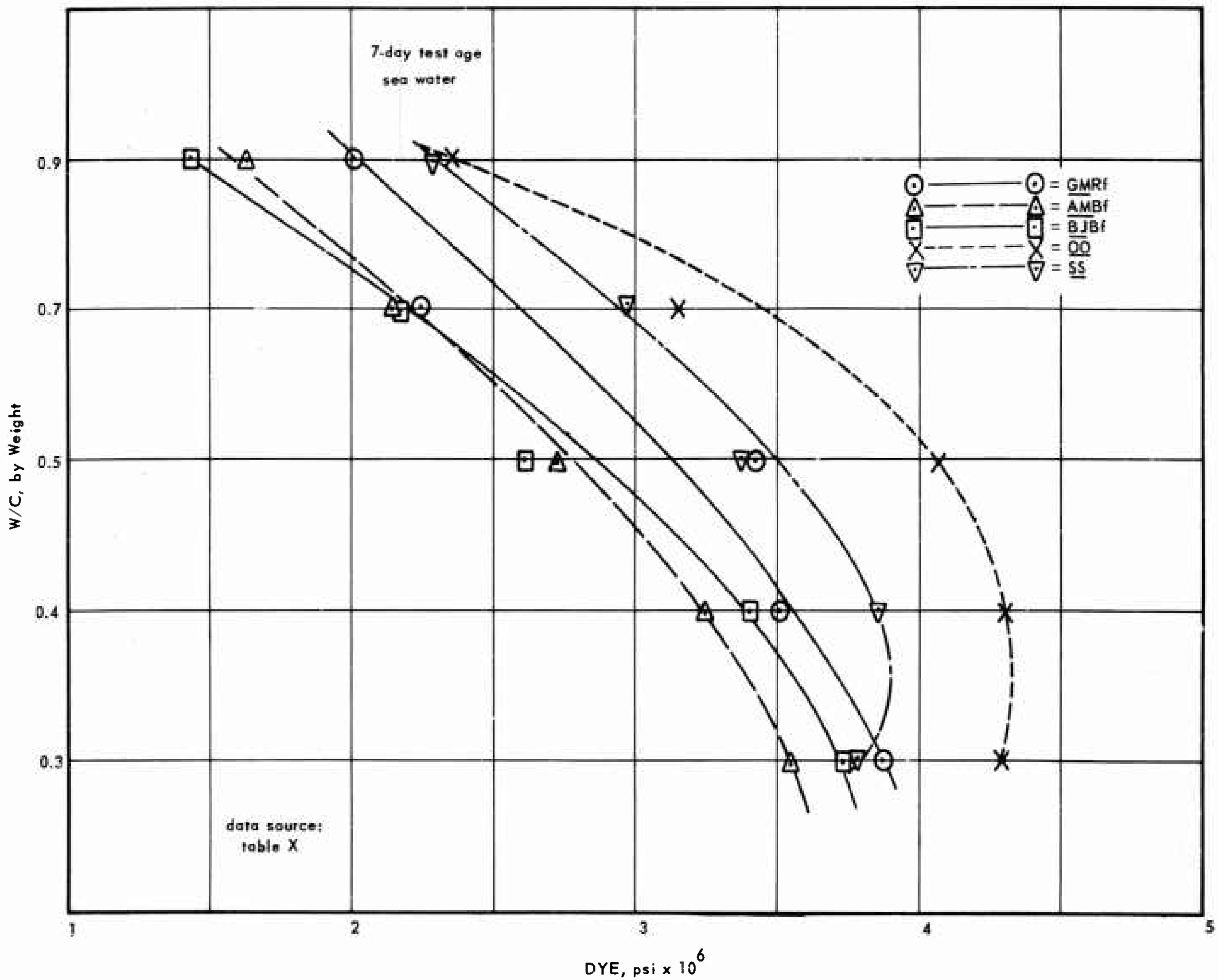

Figure 61. Correlation 8g-a'. (Part 1 of 4)

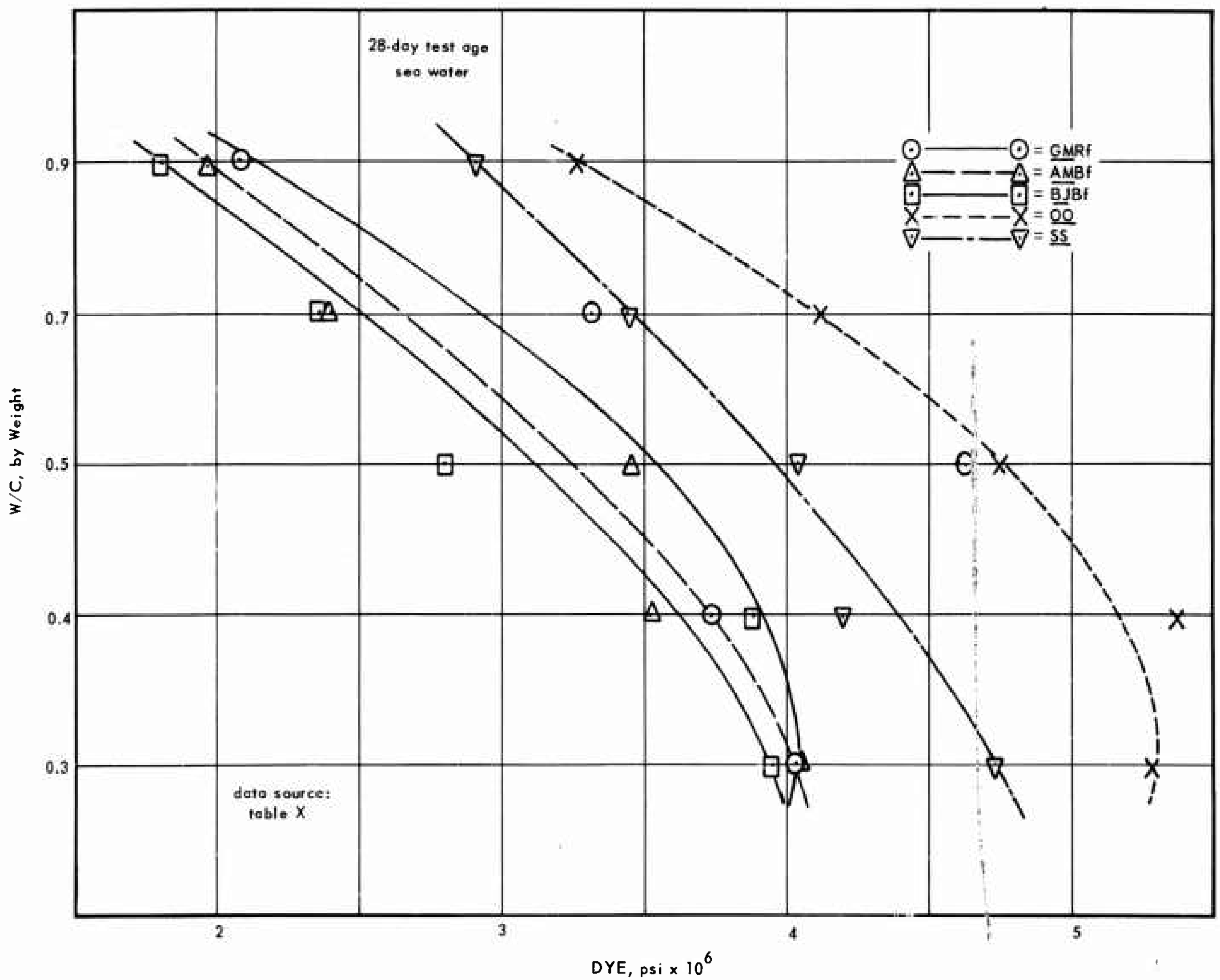

Figure 61. Correlation 8g-a'. (Part 2 of 4)

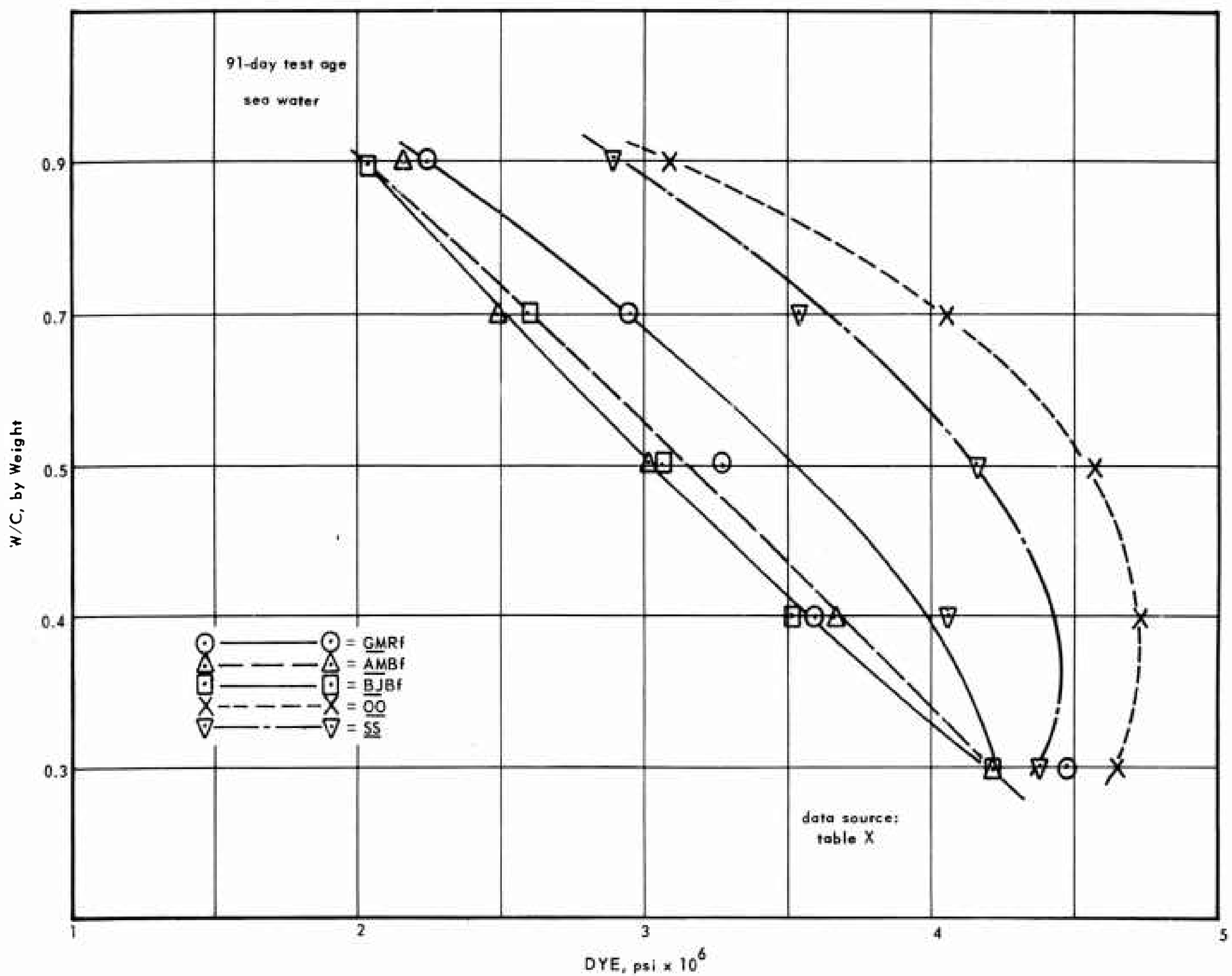

Figure 61. Correlation 8g-a'. (Part 3 of 4)

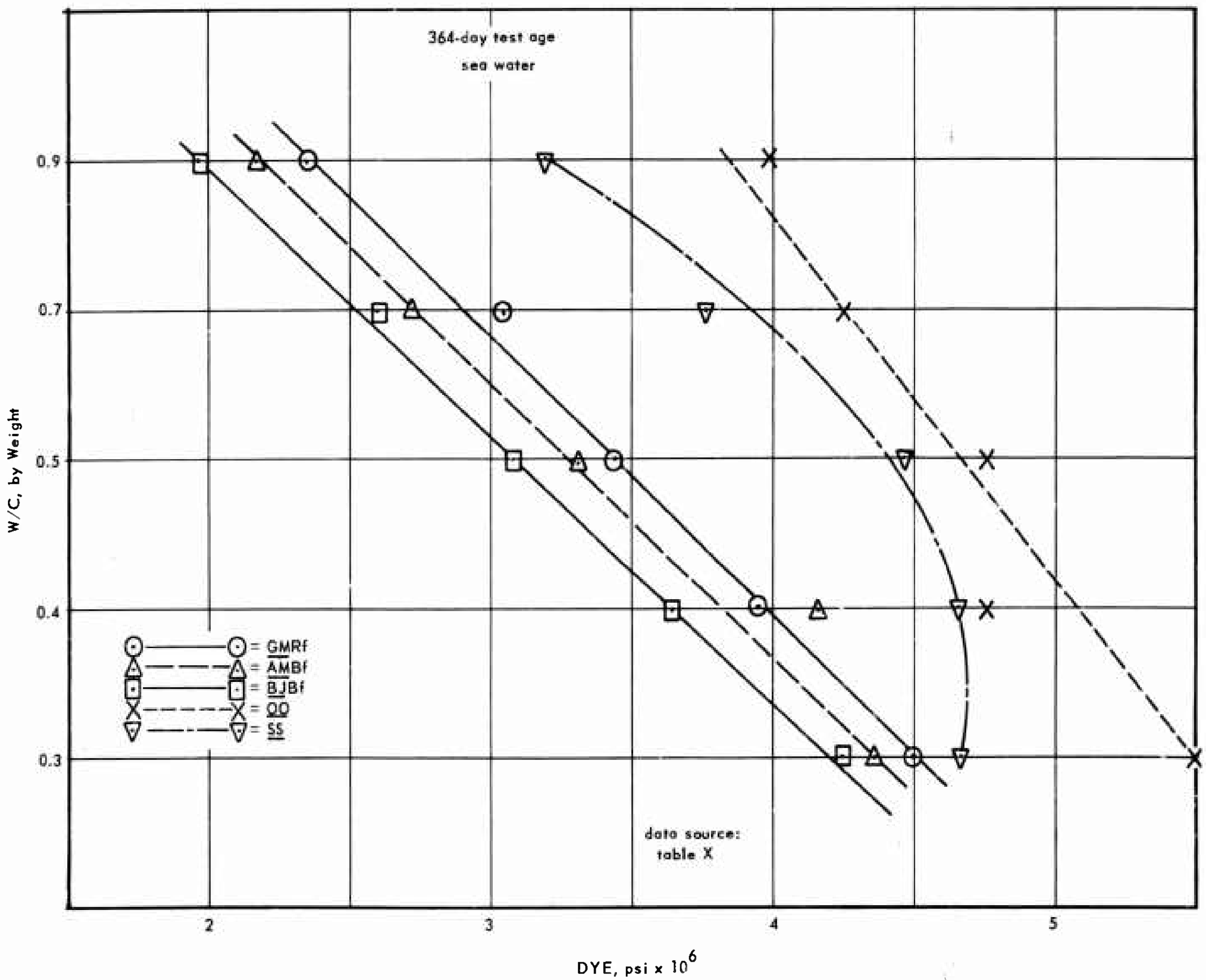

Figure 61. Correlation 8g-a'. (Part 4 of 4)

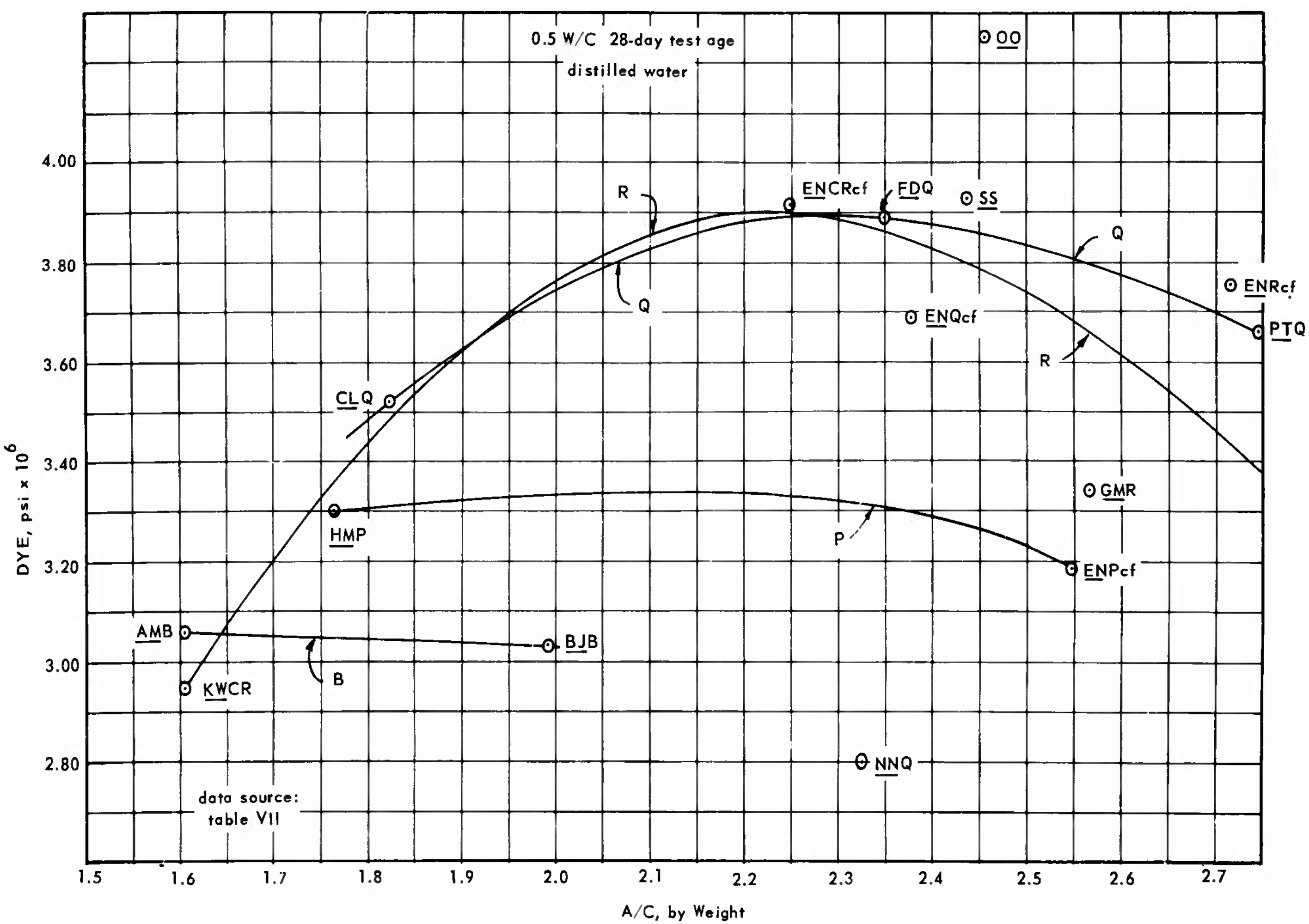

Figure 62. Correlation 8h-a'.

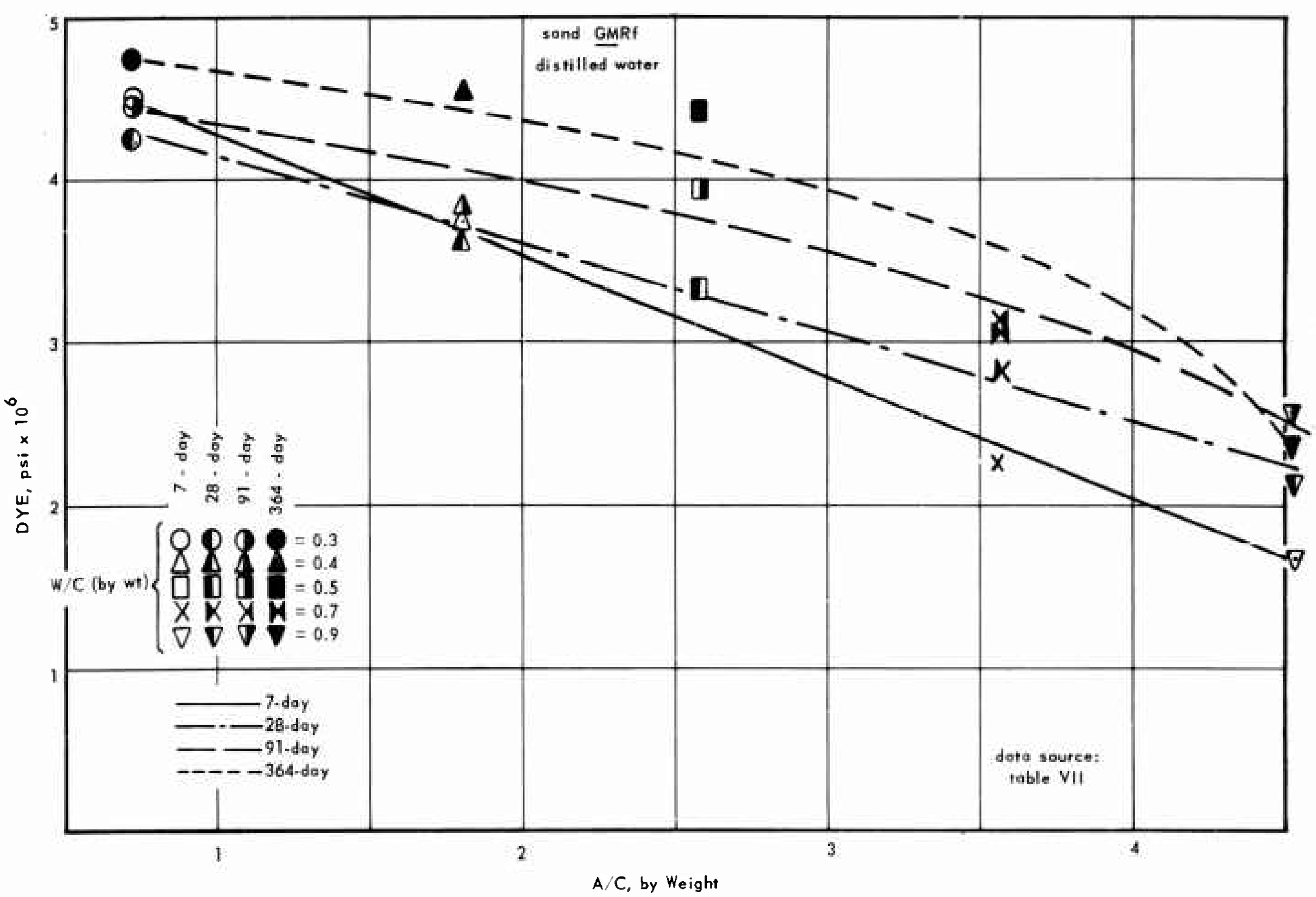

Figure 63. Correlation 8h-a'. (Part 1 of 3)

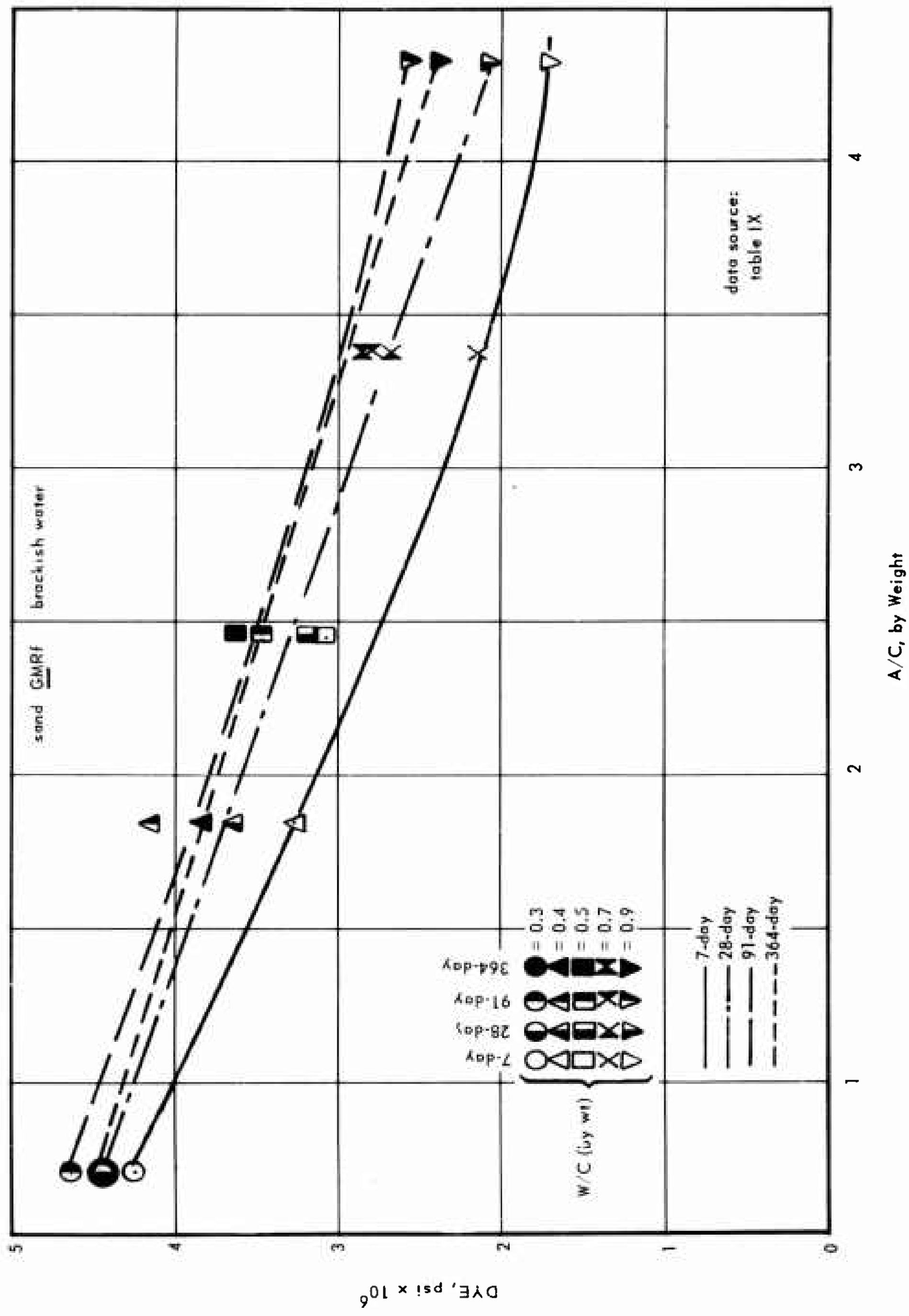

Figure 63. Correlation 8h-a'. (Part 2 of 3)

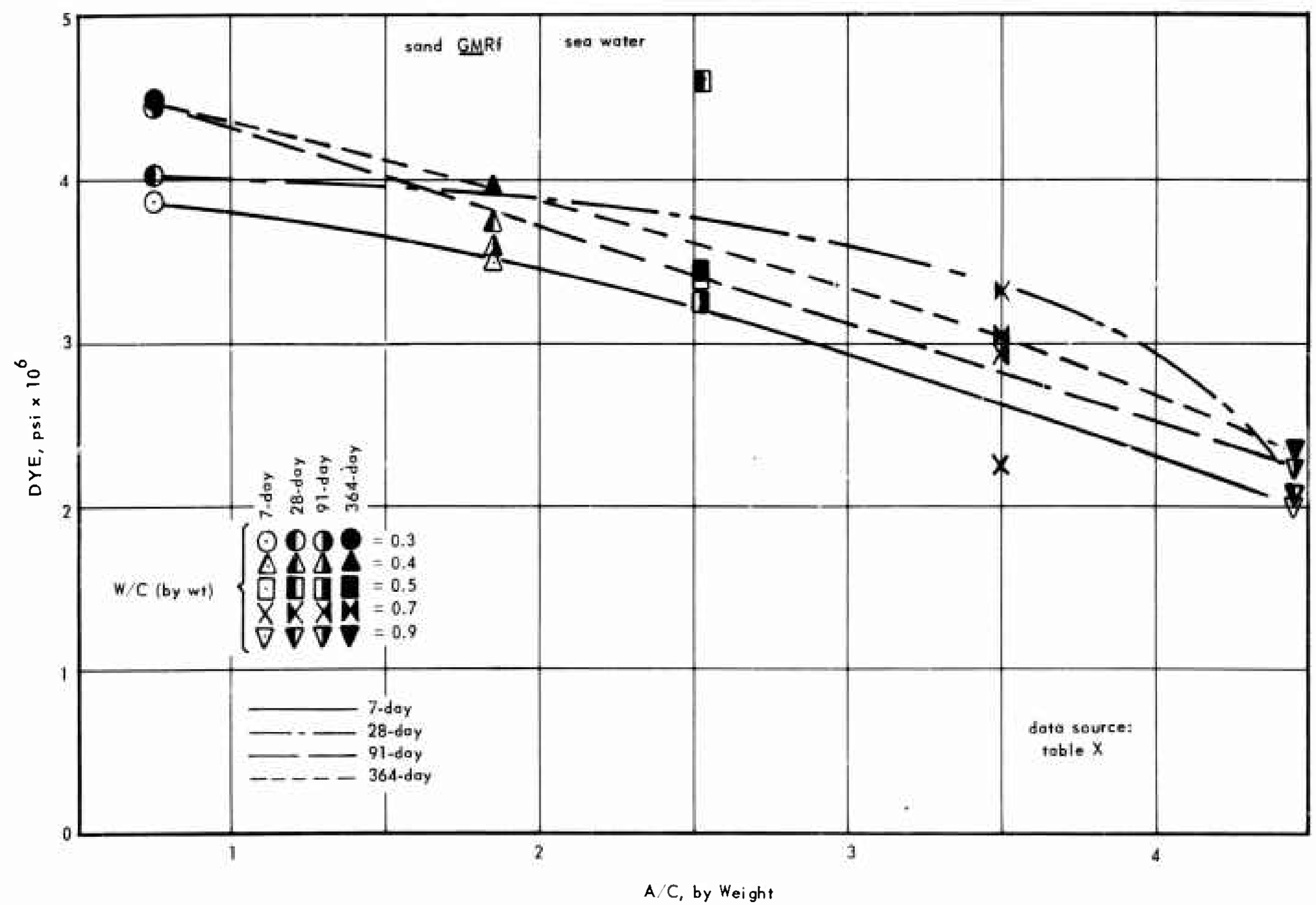

Figure 63. Correlation 8h-a'. (Part 3 of 3)

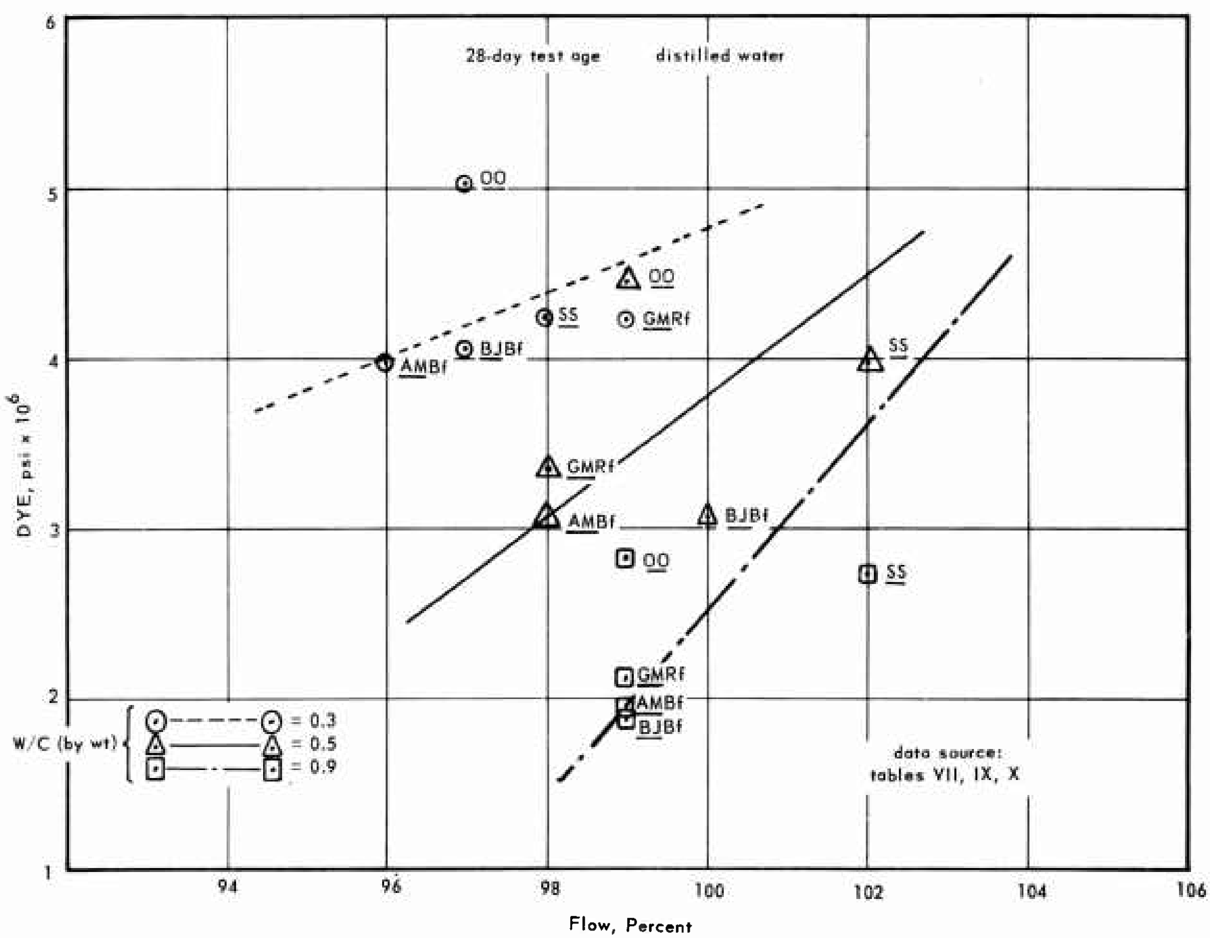

Figure 64. Correlation 8i-a'. (Part 1 of 3)

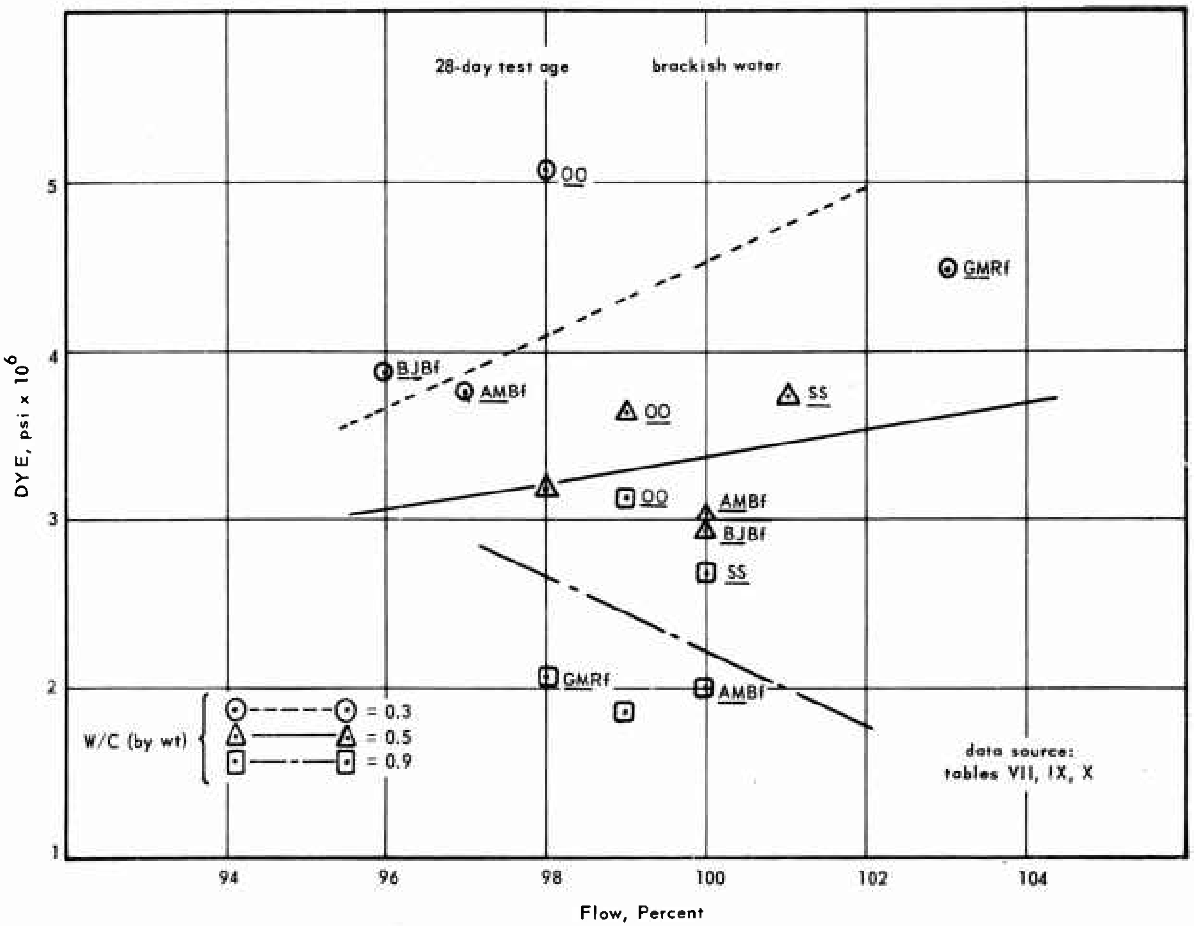

Figure 64. Correlation 8i-a'. (Part 2 of 3)

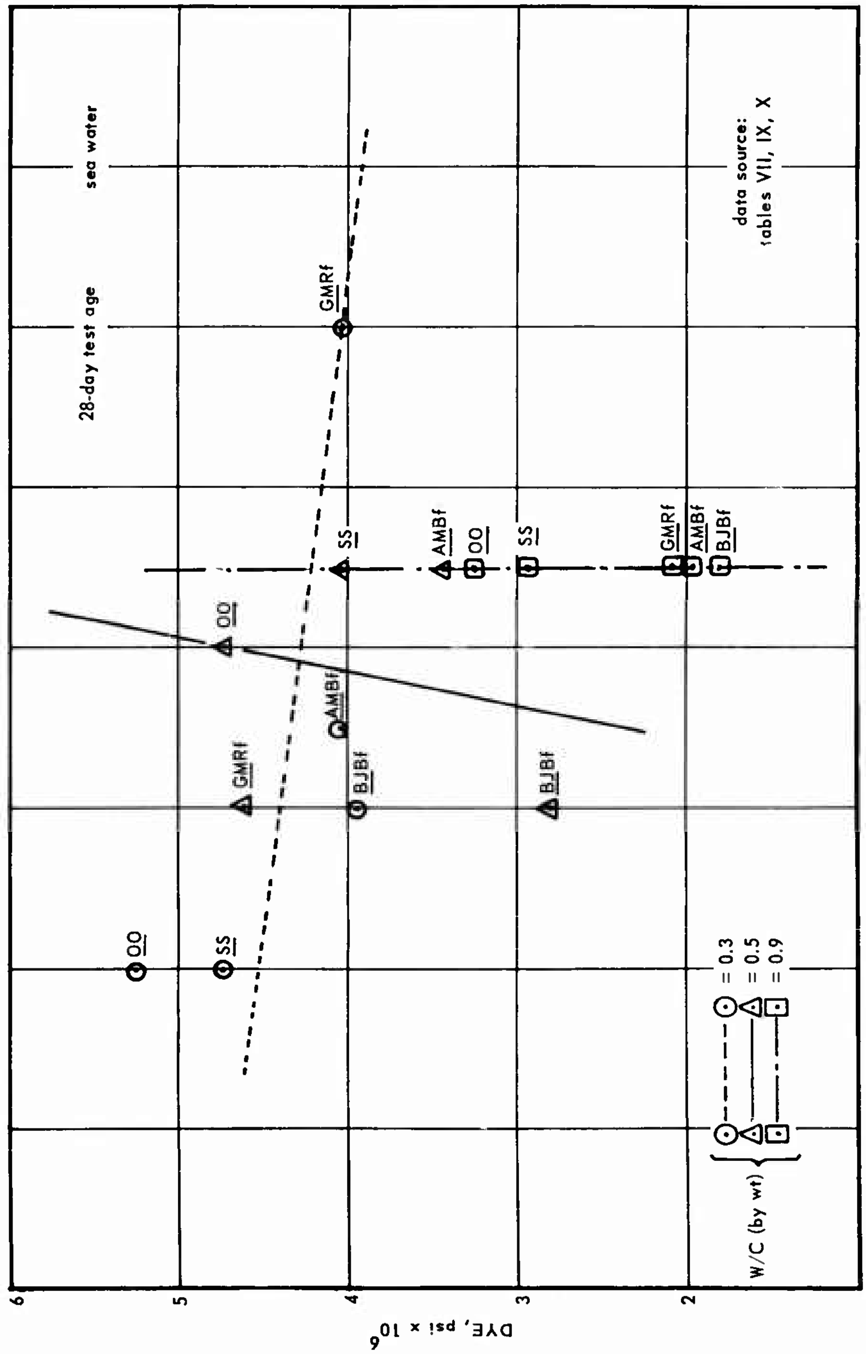

Figure 64. Correlation 8i-a'. (Part 3 of 3)

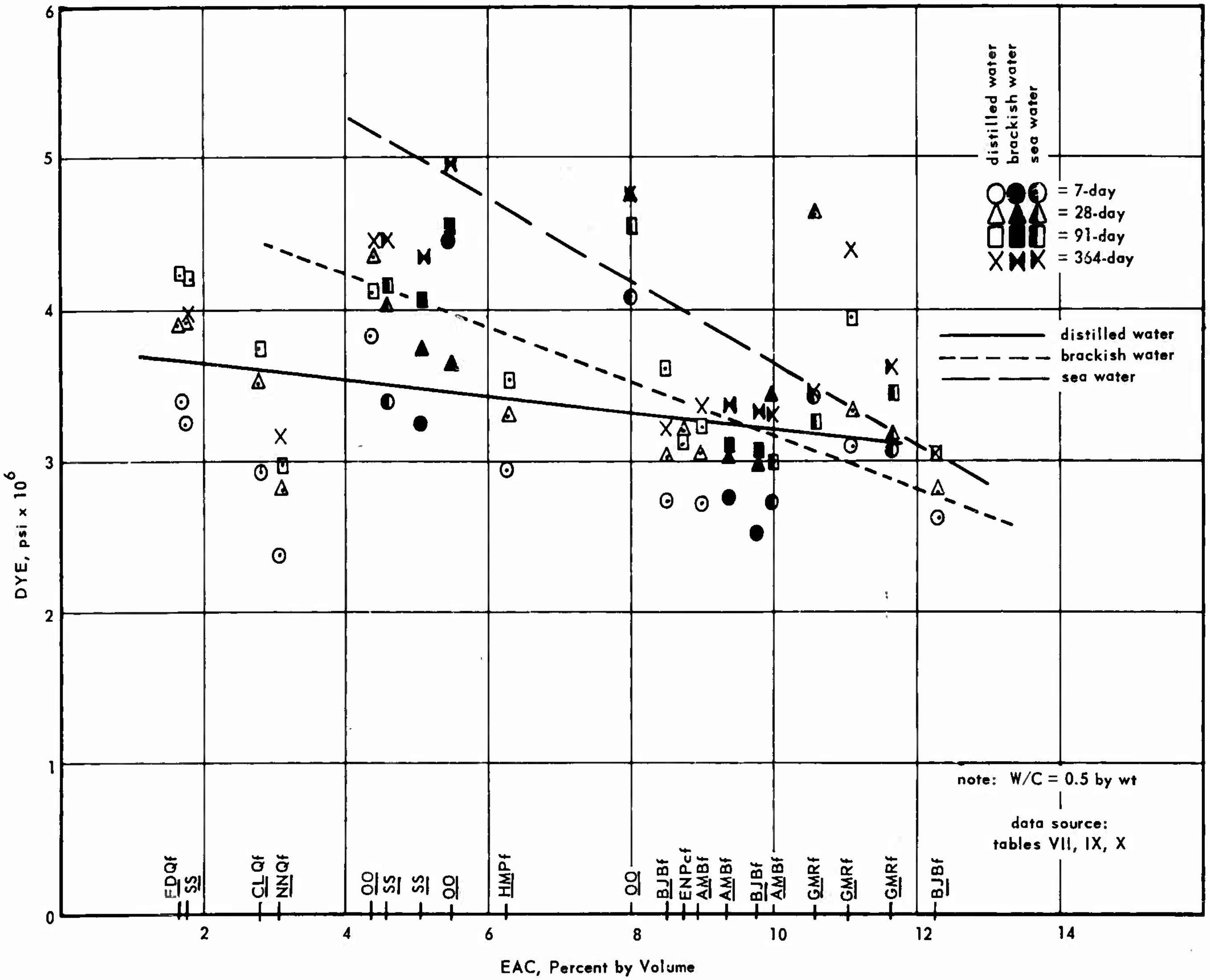

Figure 65. Correlation 8j-a'.

that of water type. DYE values for any mortar decrease at a rate of about 5 percent with each 1 percent increase in EAC when distilled water is involved in the mix; the corresponding rate of decreasing DYE is about 20 percent in the case of brackish-water mortars and about 30 percent when sea water is involved.

Correlation 8a-b'.

Regardless of sand derivation, mortars that incorporate sea water suffer considerable loss in FLS (flexural strength or rupture modulus of mortar in the solid state) with increasing age when the W/C is 0.3. As shown in Figures 66 to 70, inclusive, in such cases the FLS reduction begins at any age less than 28 days. At intermediate and high W/C values the water type exerts no unusual influence upon the rupture modulus of coral or reference mortars. In all cases investigated there is evidence of general reduction in FLS after age 91 days.

Correlation 8b-b'.

Examination of Figure 71 indicates generally that the influence of R-, B-, or P-derived coral sands is approximately equal with respect to the FLS characteristics of mortars incorporating distilled water. The use of Q-derived (quarry source) coral sands in conjunction with distilled water appears most desirable at intermediate W/C values in view of the ever-increasing flexural strength with increasing age. Whether or not this trend of Q-derived coral sand mortars would be evident at extremely low or high W/C values is conjectural, as no supporting data are available. But the FLS performance of mortars fabricated with Q-derived coral sand is noteworthy at intermediate W/C values; those fabricated with R-derived coral sand appear most promising at high W/C values.

Correlation 8c-b'.

The rate at which FLS of mortars fabricated with P- or Q-derived coral sands diminishes, with increasing percent voids, is about ten times the corresponding rate for mortars made with B- or R-derived coral sands. This interpretation is valid at age 28 days when the water is distilled, the W/C is 0.5, and the fine aggregate is natural-graded; this relationship is portrayed in Figure 72. Similar trends for other mixes at other ages can be deduced from the data sources indicated.

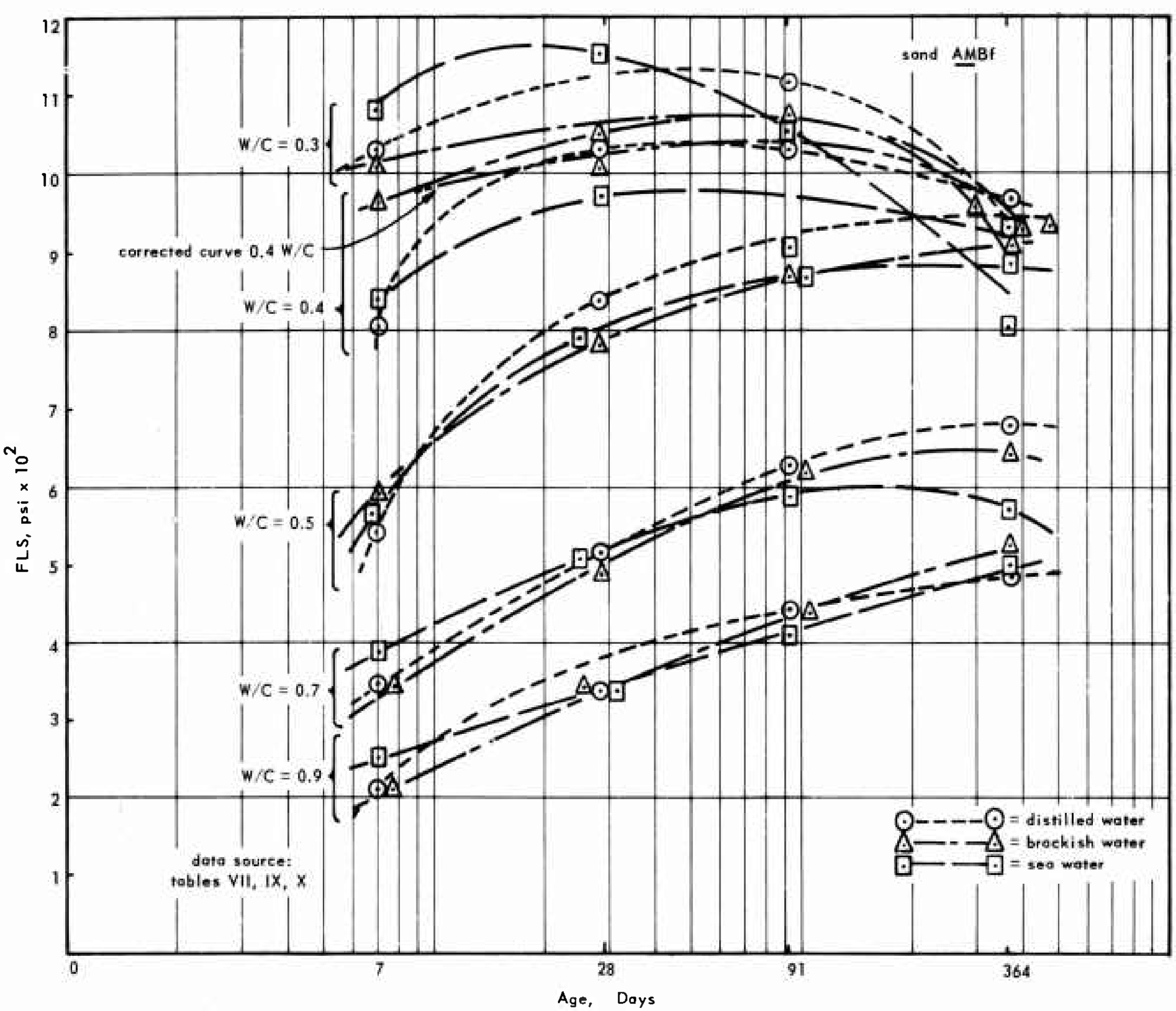

Figure 66. Correlation 8a-b'.

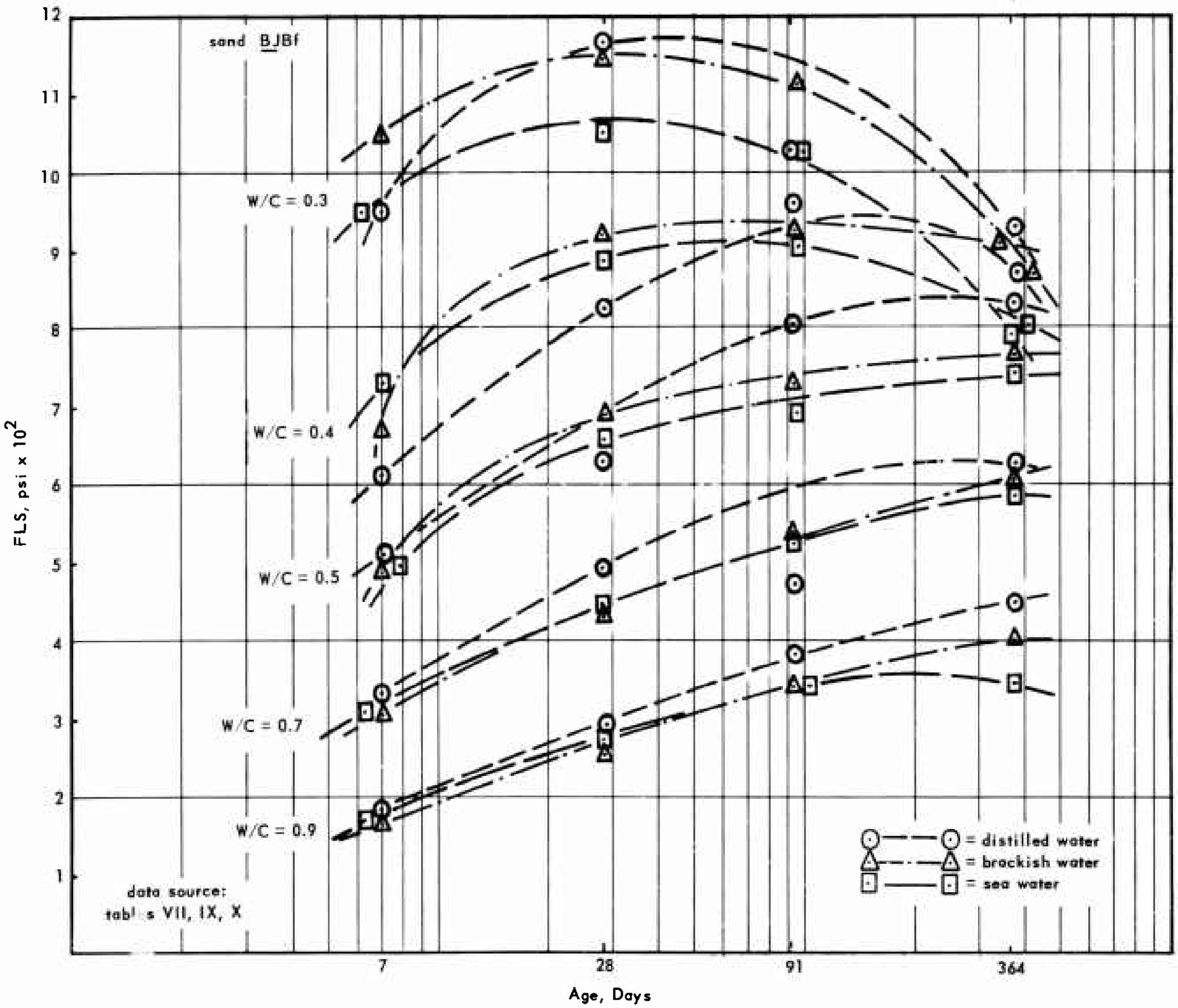

Figure 67. Correlation 8a-b'.

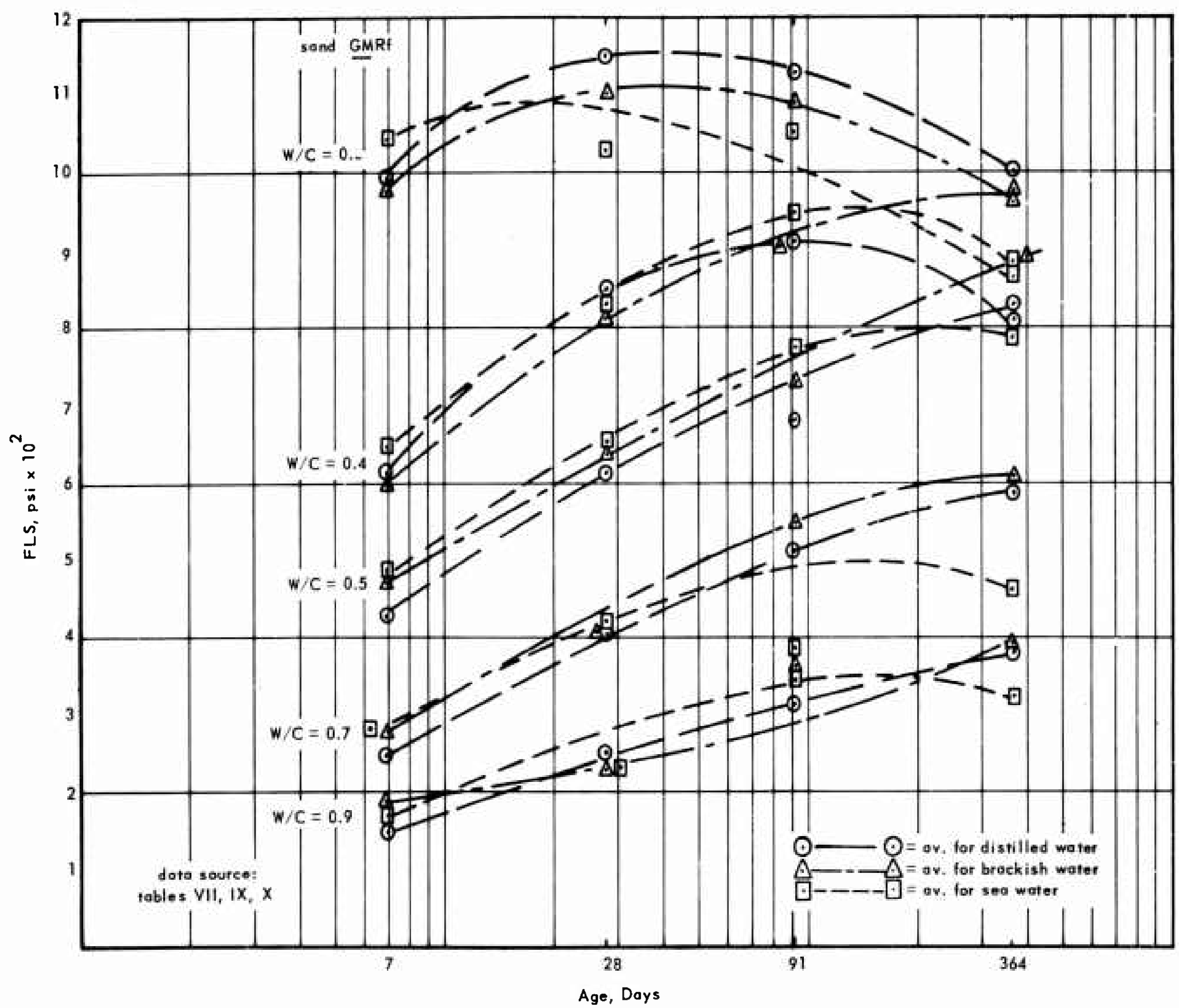

Figure 68. Correlation 8a-b'.

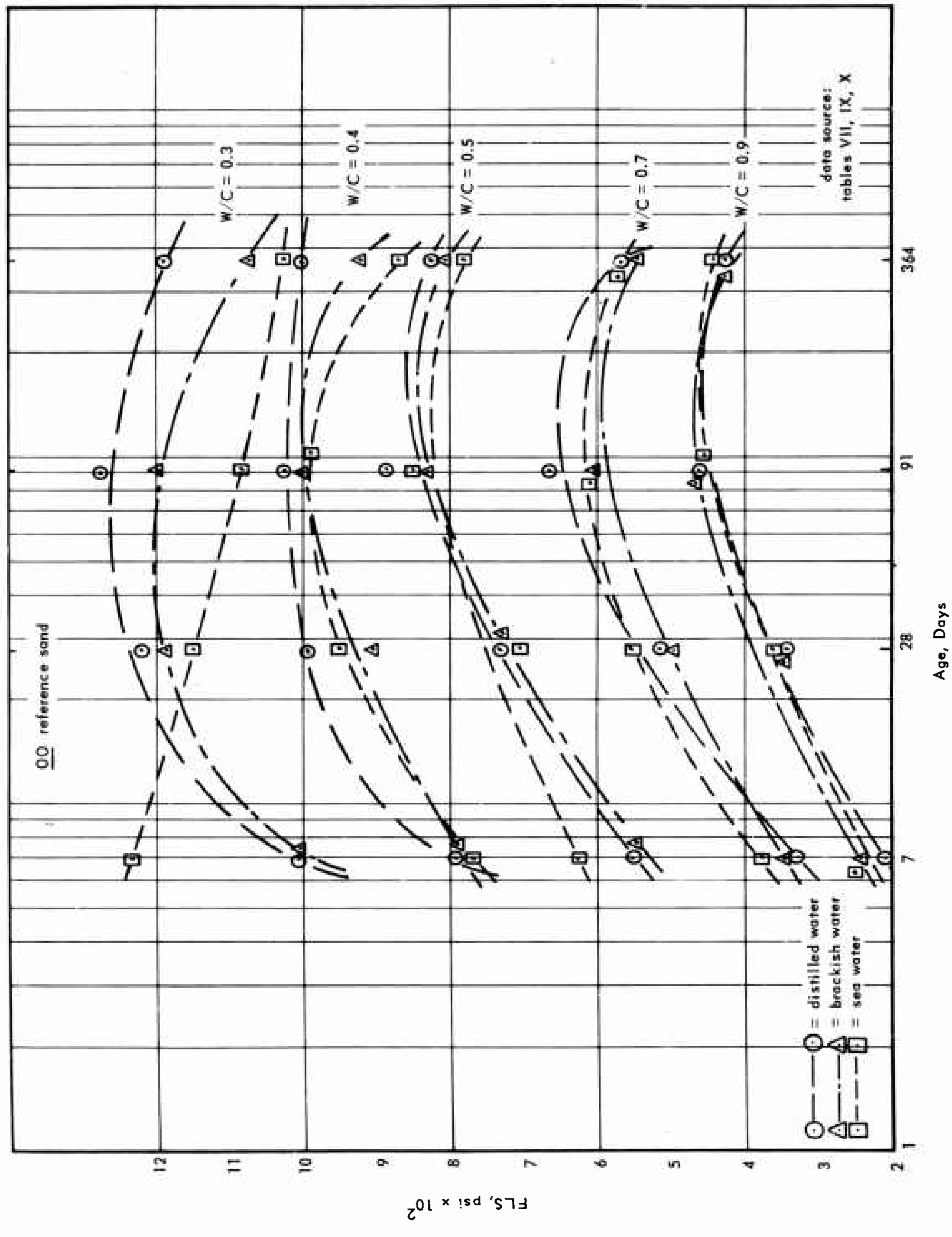

Figure 69. Correlation 8a-b'.

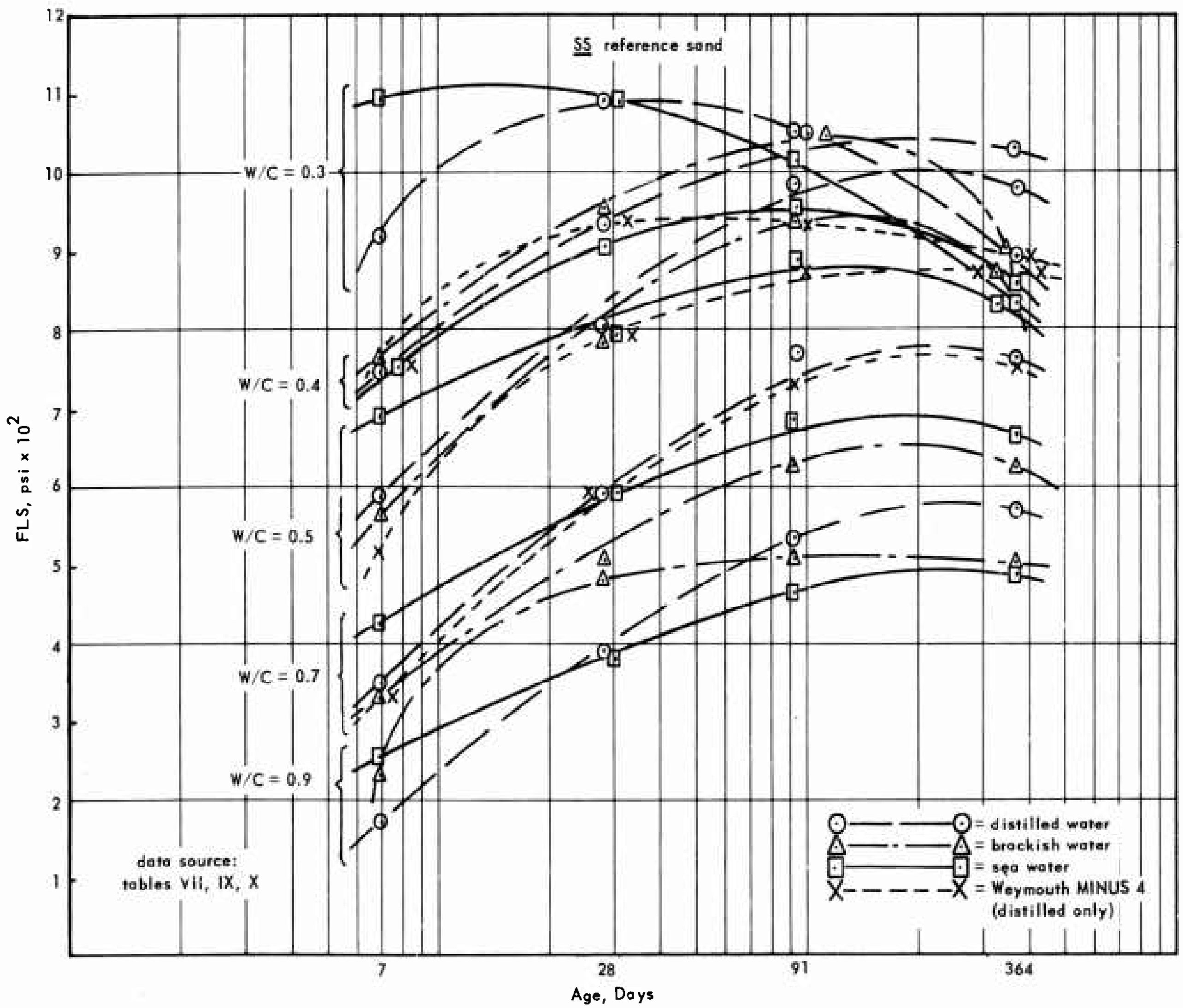

Figure 70. Correlation 8a-b'.

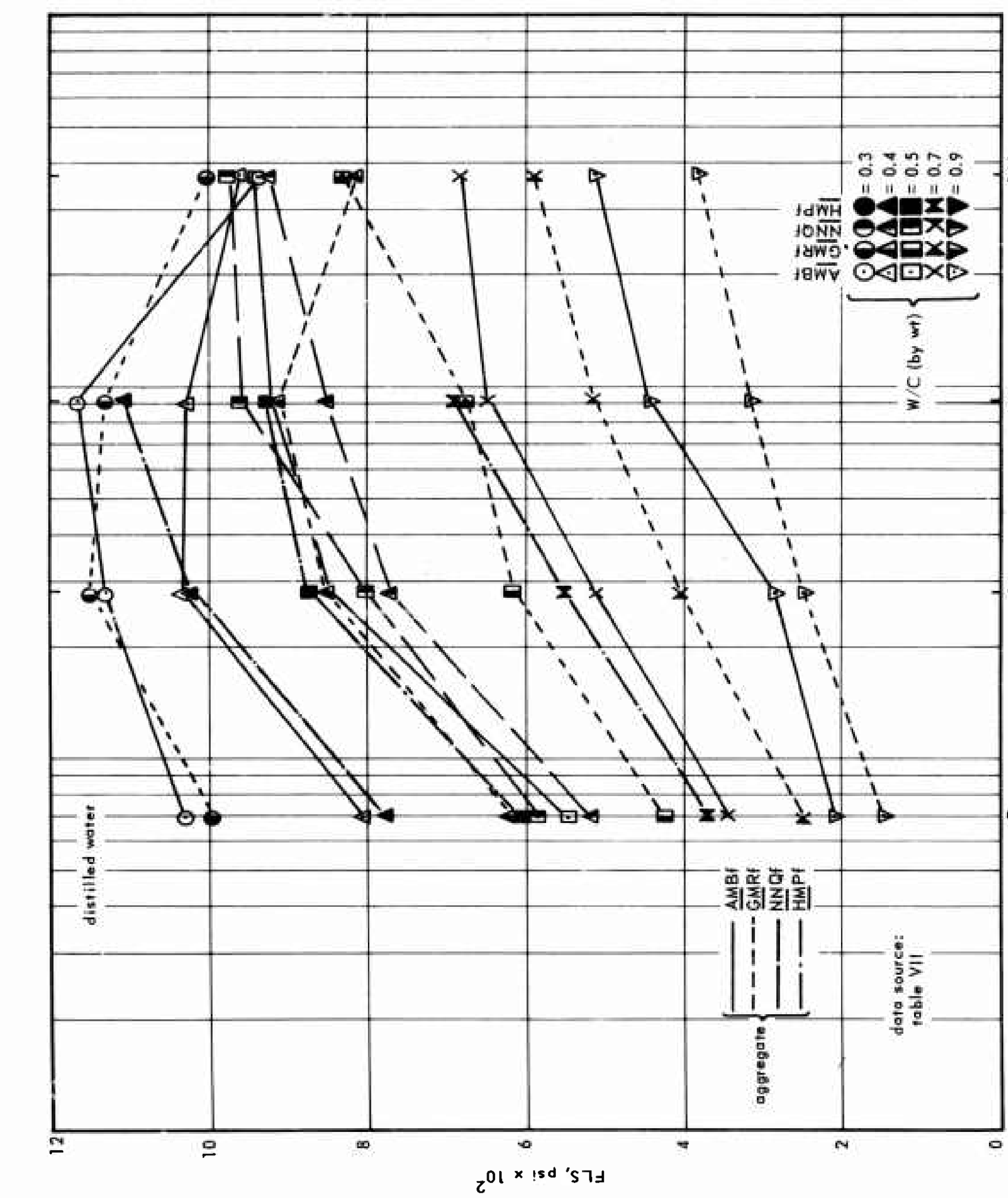

Figure 71. Correlation 8b-b'.

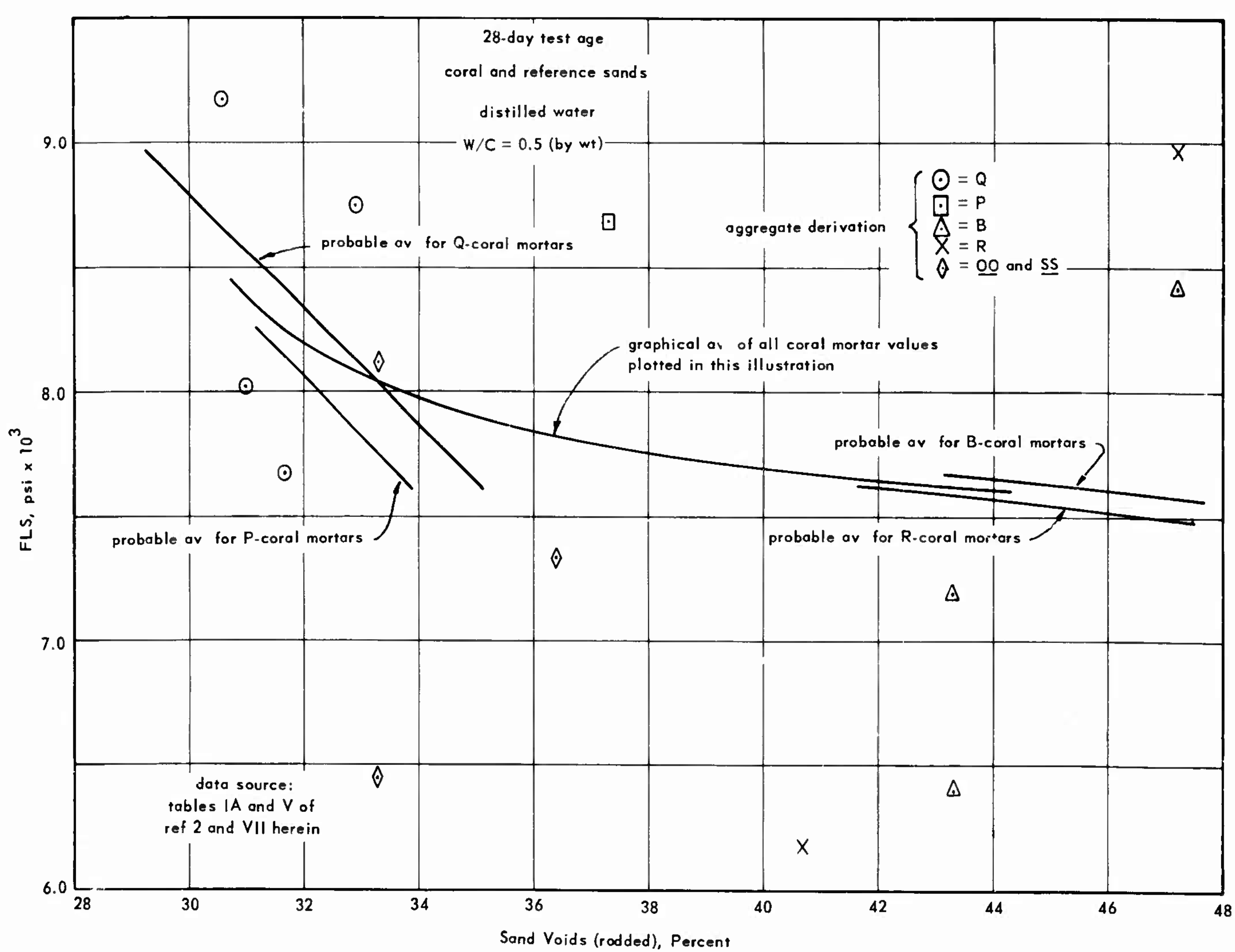

Figure 72. Correlation 8c-b'.

Correlation 8d-b'.

Despite the statements in Section 2, it is noted (Table VIII) that, in the case of mortars made with sands conforming to Weymouth's curve, R-derived coralline materials exhibit highest FLS values when the W/C is 0.5. This trend is in contradistinction to that observed in Correlation 8b-b' where natural-graded Q-derived coral sands appear most promising.

Correlation 8e-b'.

The graphical relationship between CCS of variously derived sands and the FLS characteristics of 28-day-old mortars, incorporating those sands and distilled water and mixed on the basis of a W/C of 9.5, appears in Figure 73. Examination of this graph suggests the approximate ranges in FLS attainable when R-, B-, or Q-derived coral sands are employed in the mortars. It appears that B-derived coral sands may be most desirable with respect to this correlation; as shown in Reference 2, considerable variation in CCS can be expected with identically derived coralline materials from the same geographical source, and in this instance R- and Q-derived materials apparently tend toward greater variations than do B-derived materials.

Correlation 8f-b'.

Although this relationship is shown in Table I as being insignificant with regard to correlativity, examination of Table XV of Reference 2 and Table VIII herein discloses that in the case of distilled water and ideal-graded coral reef fine aggregate, the FLS of the resultant mortar at age 28 days is increased about one-fourth as the predominant particle shape changes from subround to angular. This comparison is valid, of course, as long as the FM values remain equal.

Correlation 8g-b'.

Regardless of type of water, derivation of sand, or test age (not beyond one year), all mortars investigated in the regular series showed approximately the same variation of FLS with change in W/C. Figures 74, 75, and 76 are self-explanatory. In general, the FLS values corresponding to a W/C of 0.3 are from two to five times those for a W/C of 0.9, the factor depending upon age at loading. The factor of magnitude five (at age 7 days) decreases to magnitude two (at age 364 days). Figure 77 illustrates the same trend as observed in the preliminary series. With regard to the effect of low W/C values upon the FLS performance of mortars incorporating sea water, refer also to Correlation 8a-b'.

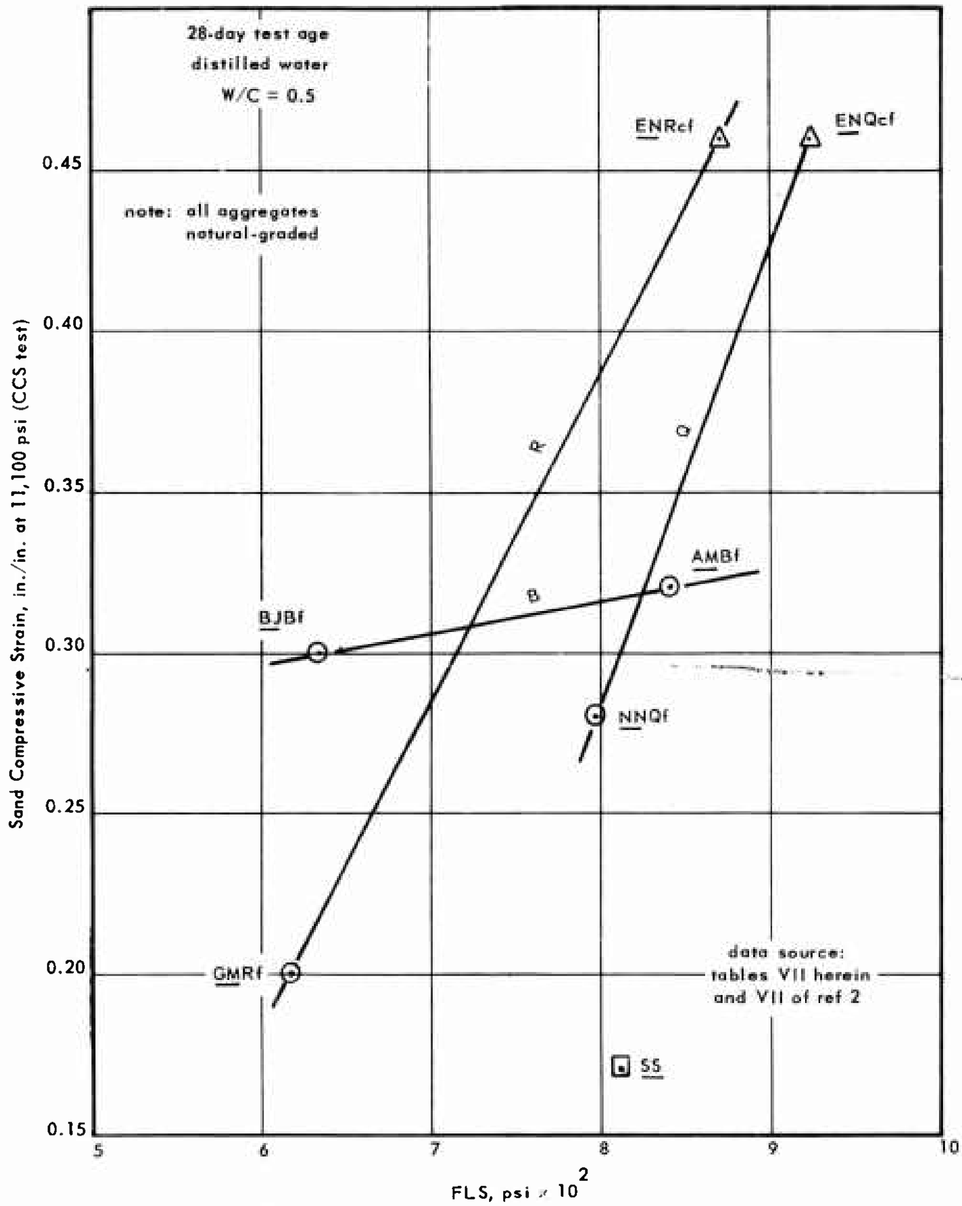

Figure 73. Correlation 8e-b'.

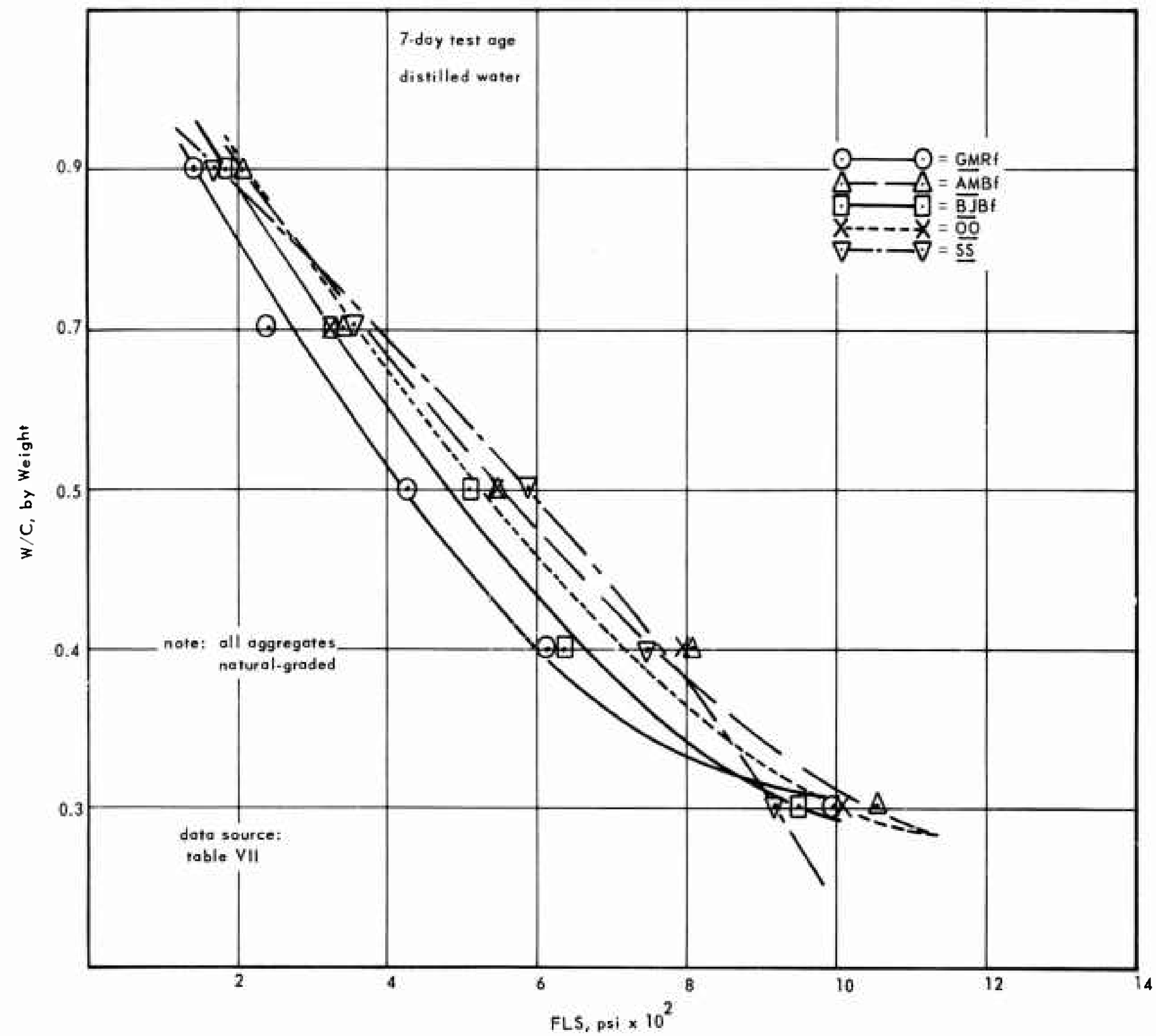

Figure 74. Correlation 8g-b'. (Part 1 of 4)

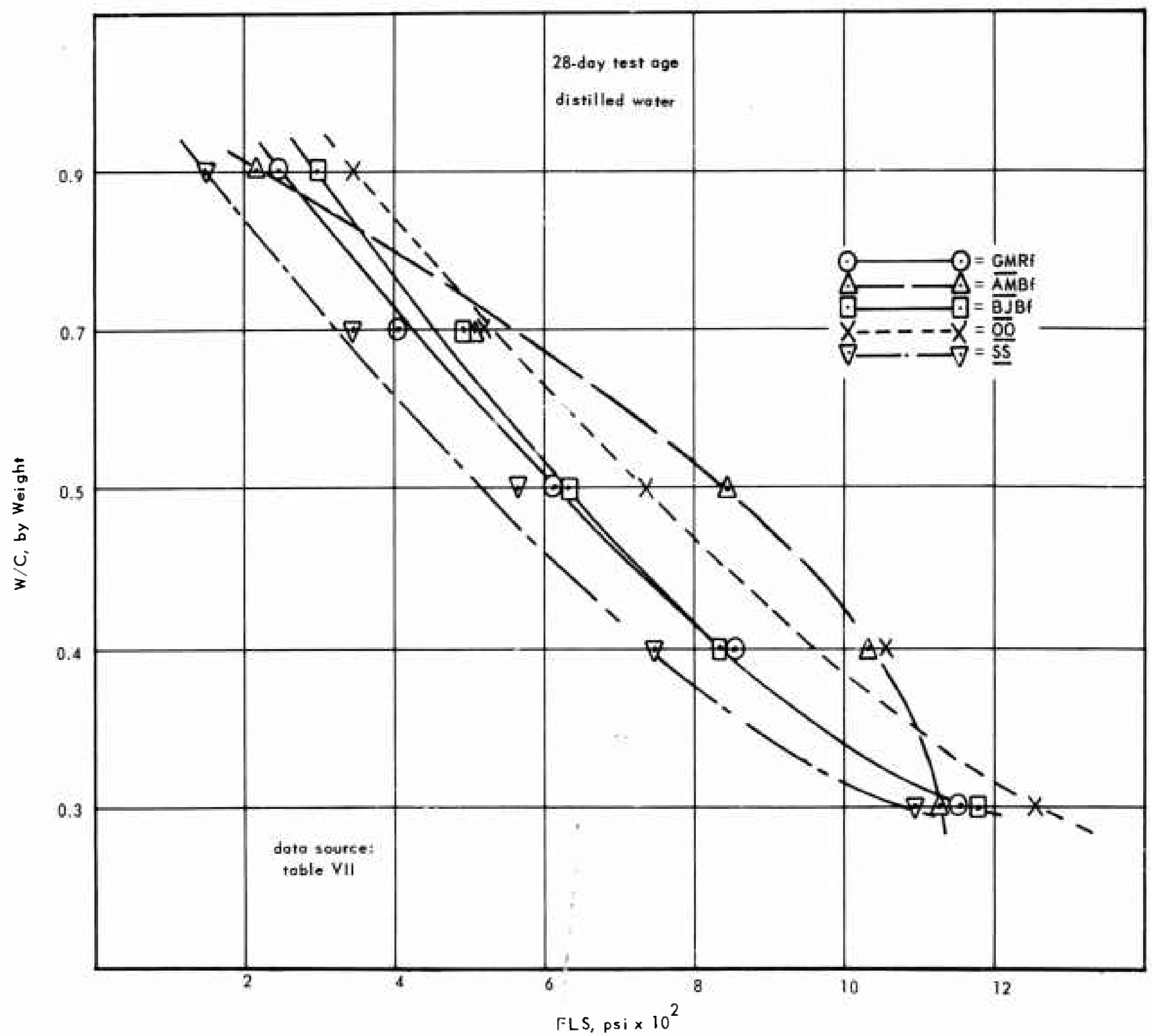

Figure 74. Correlation 8g-b'. (Part 2 of 4)

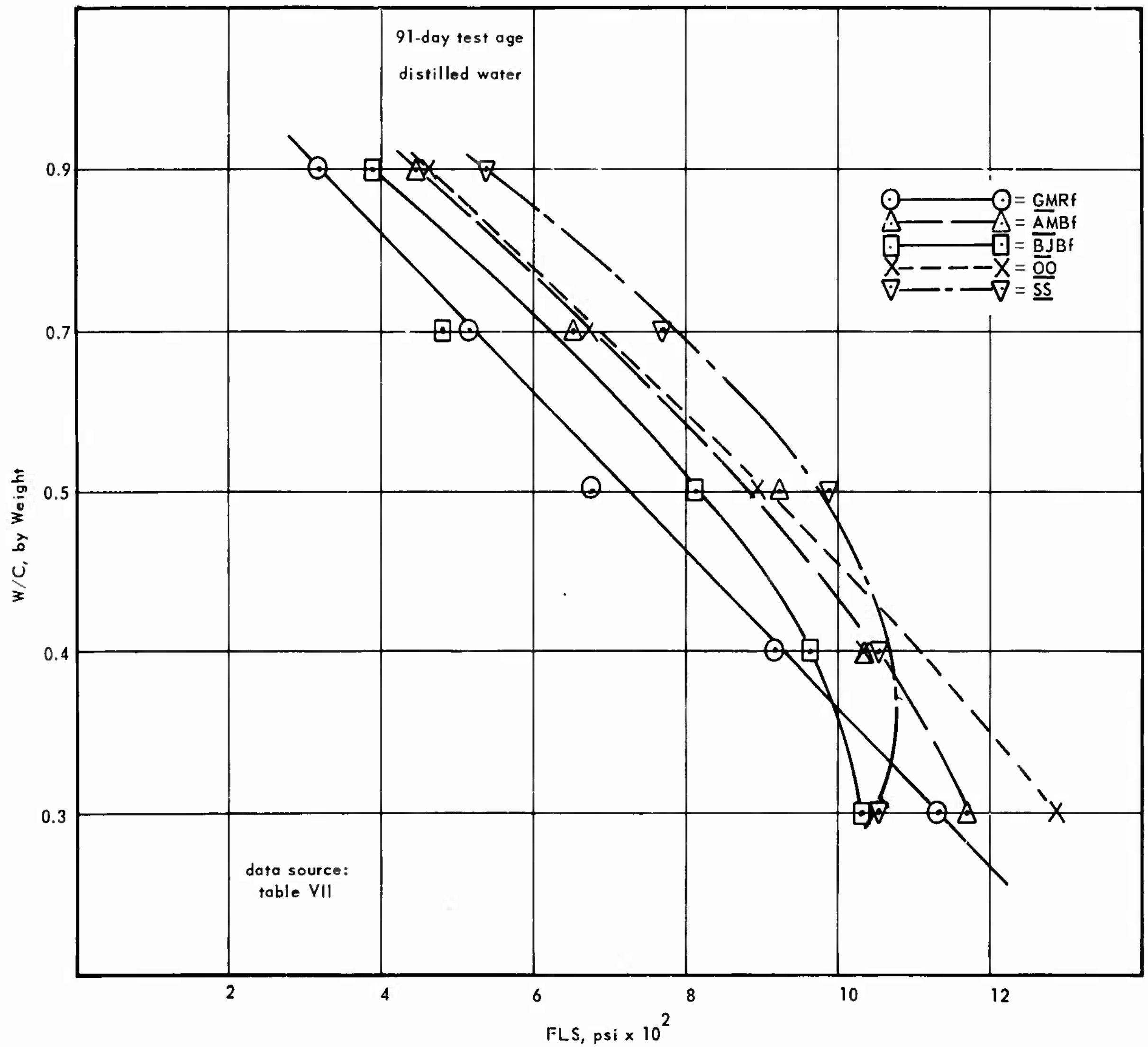

Figure 74. Correlation 8g-b'. (Part 3 of 4)

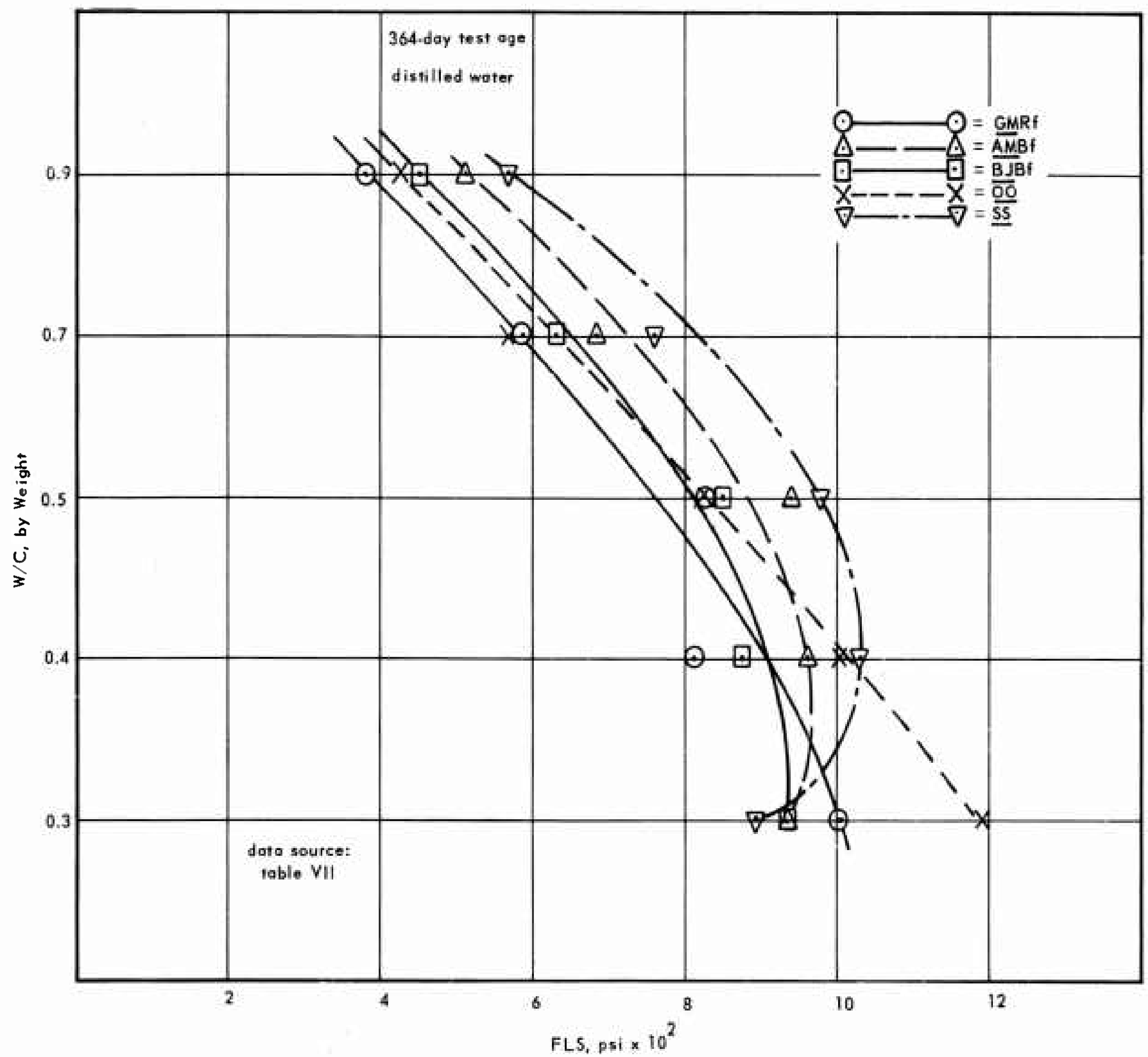

Figure 74. Correlation 8g-b'. (Part 4 of 4)

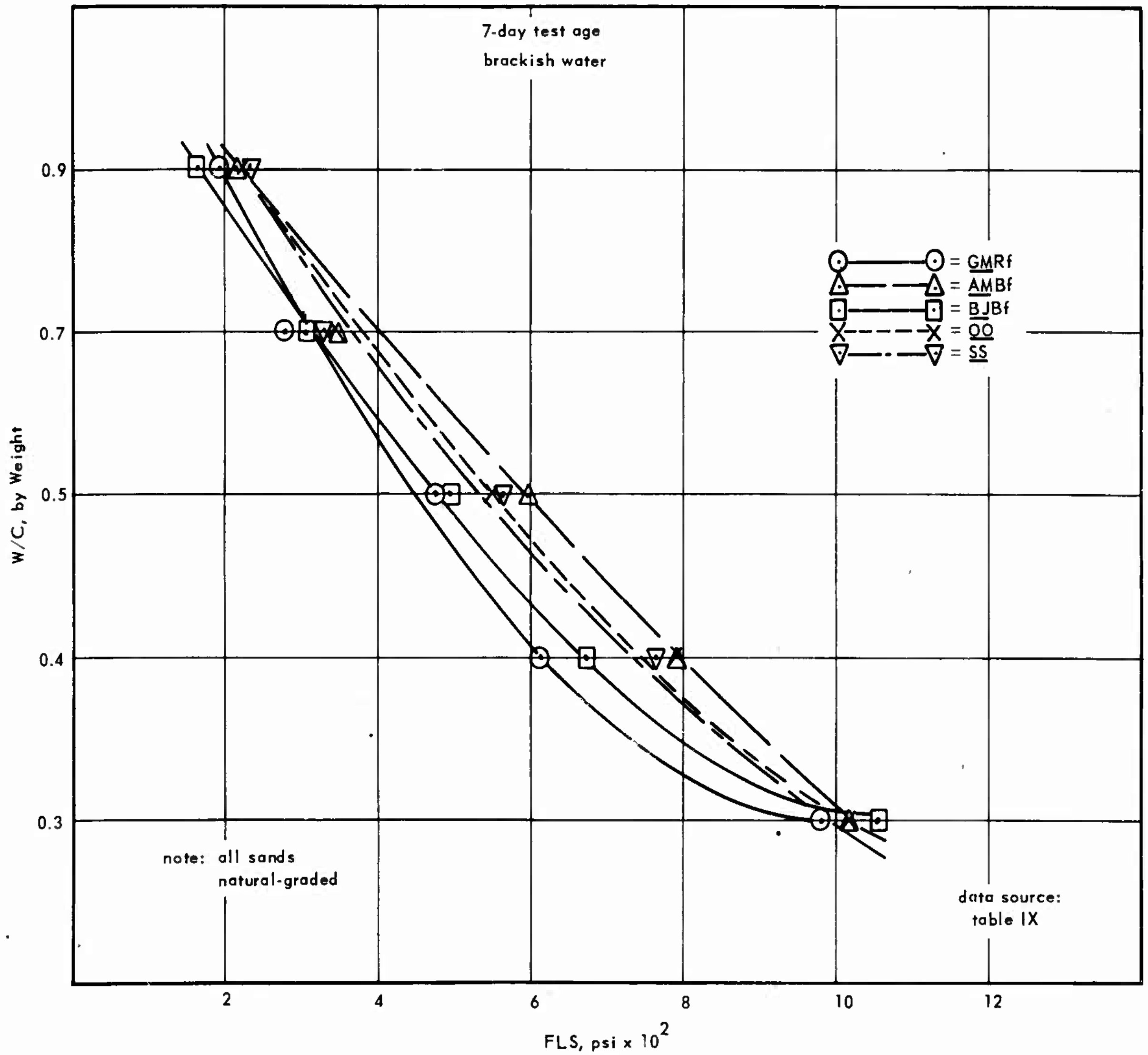

Figure 75. Correlation 8g-b'. (Part 1 of 4)

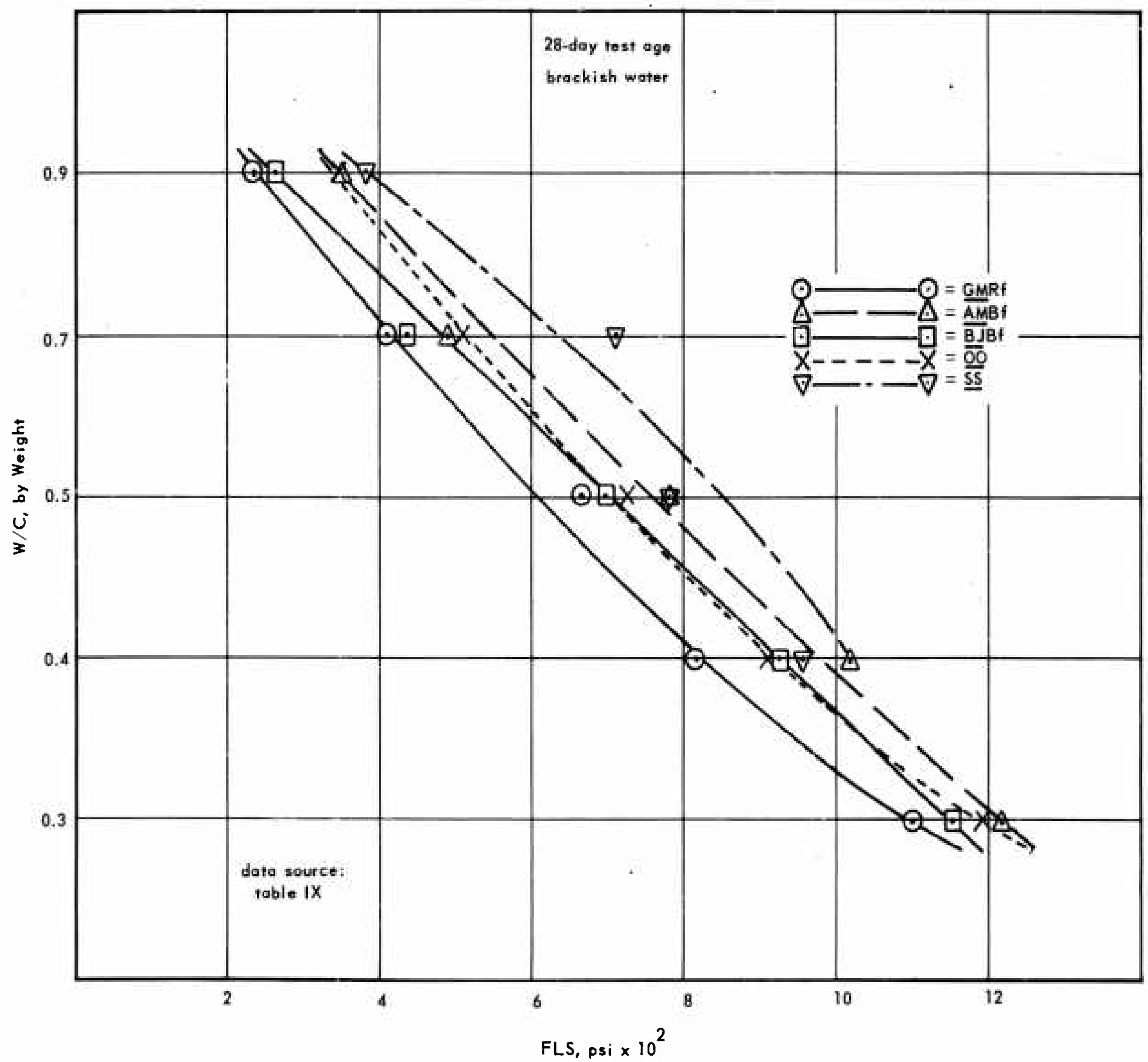

Figure 75. Correlation 8g-b'. (Part 2 of 4)

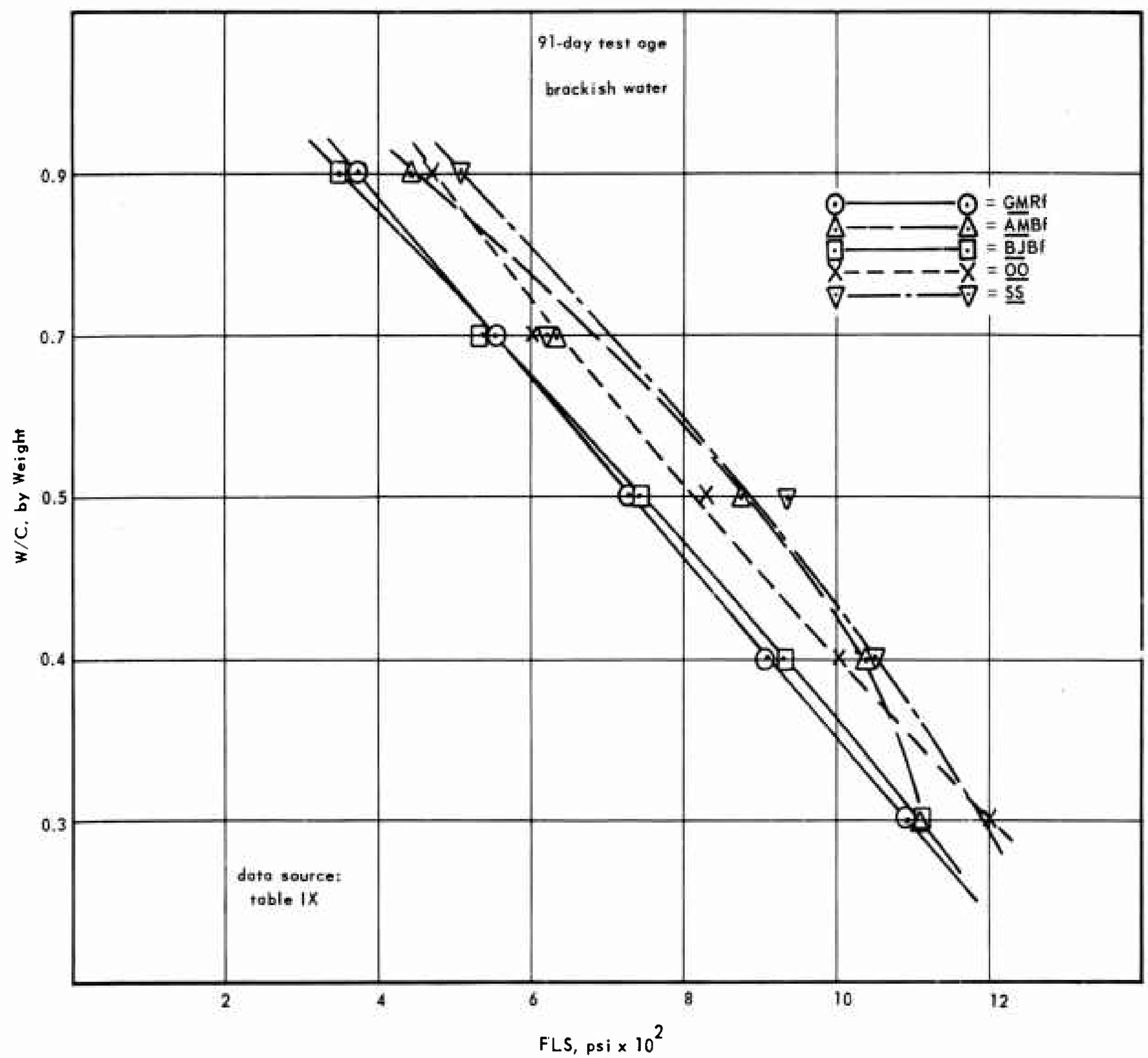

Figure 75. Correlation 8g-b'. (Part 3 of 4)

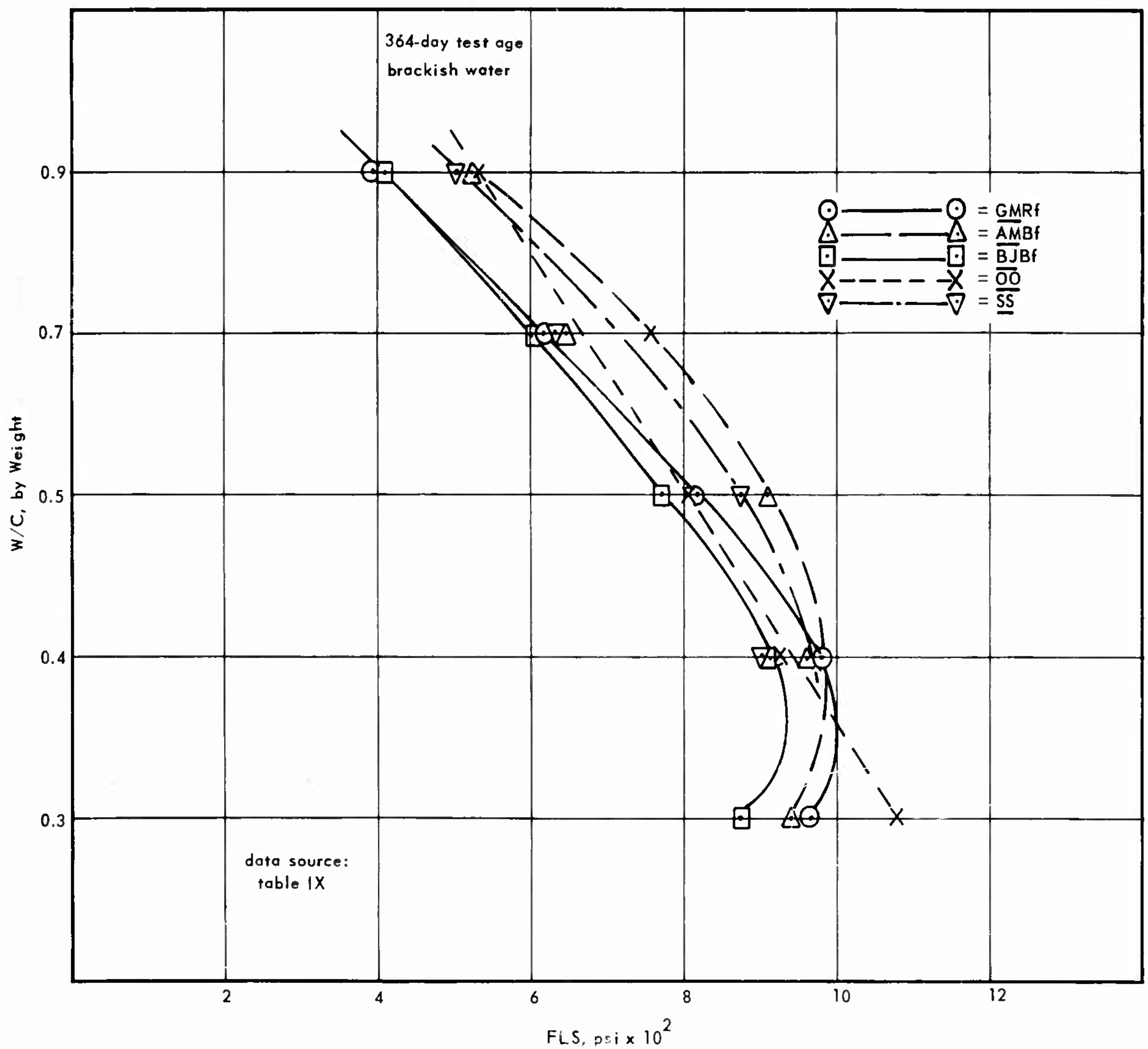

Figure 75. Correlation 8g-b'. (Part 4 of 4)

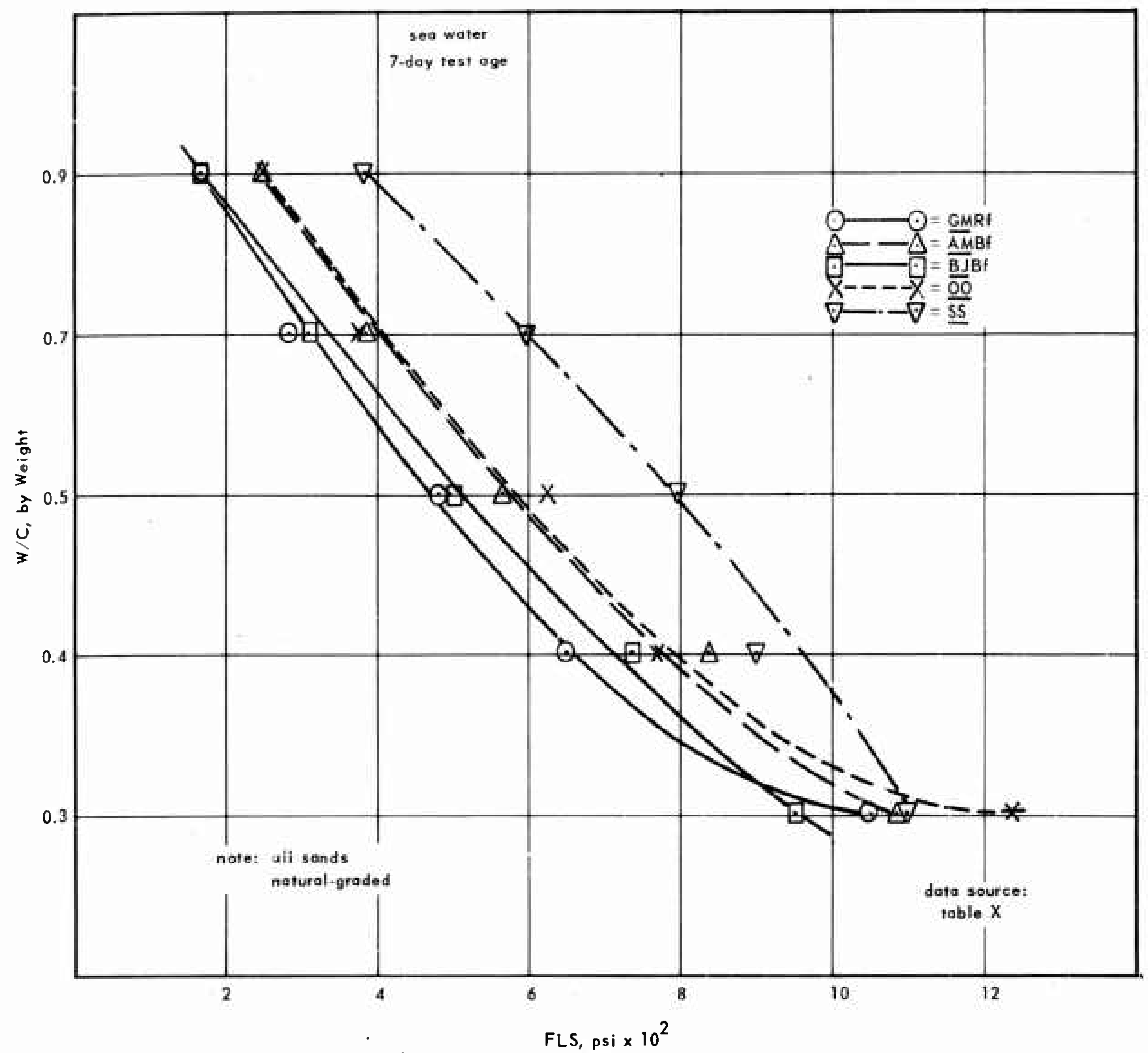

Figure 76. Correlation 8g-b'. (Part 1 of 4)

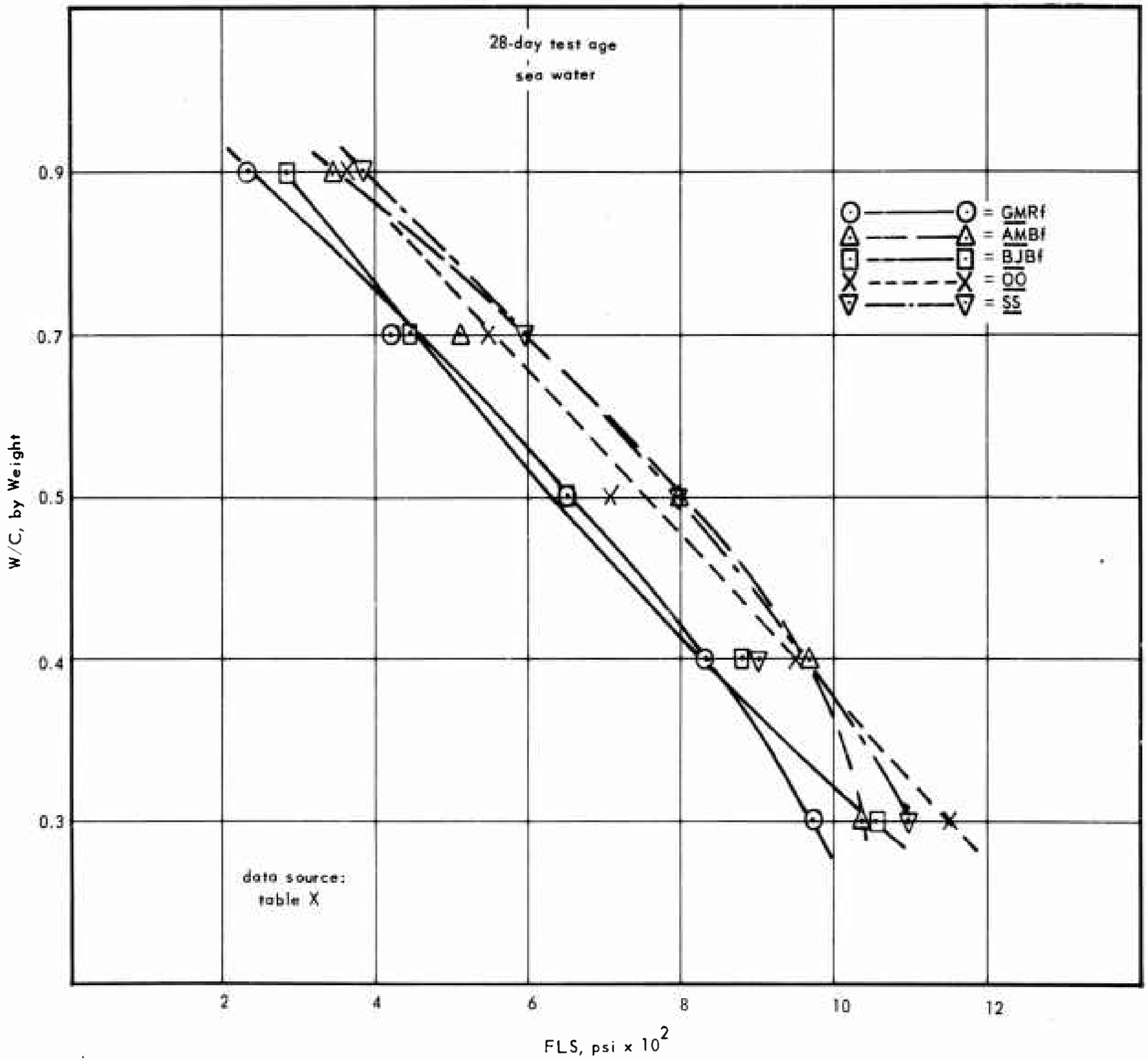

Figure 76. Correlation 8g-b'. (Part 2 of 4)

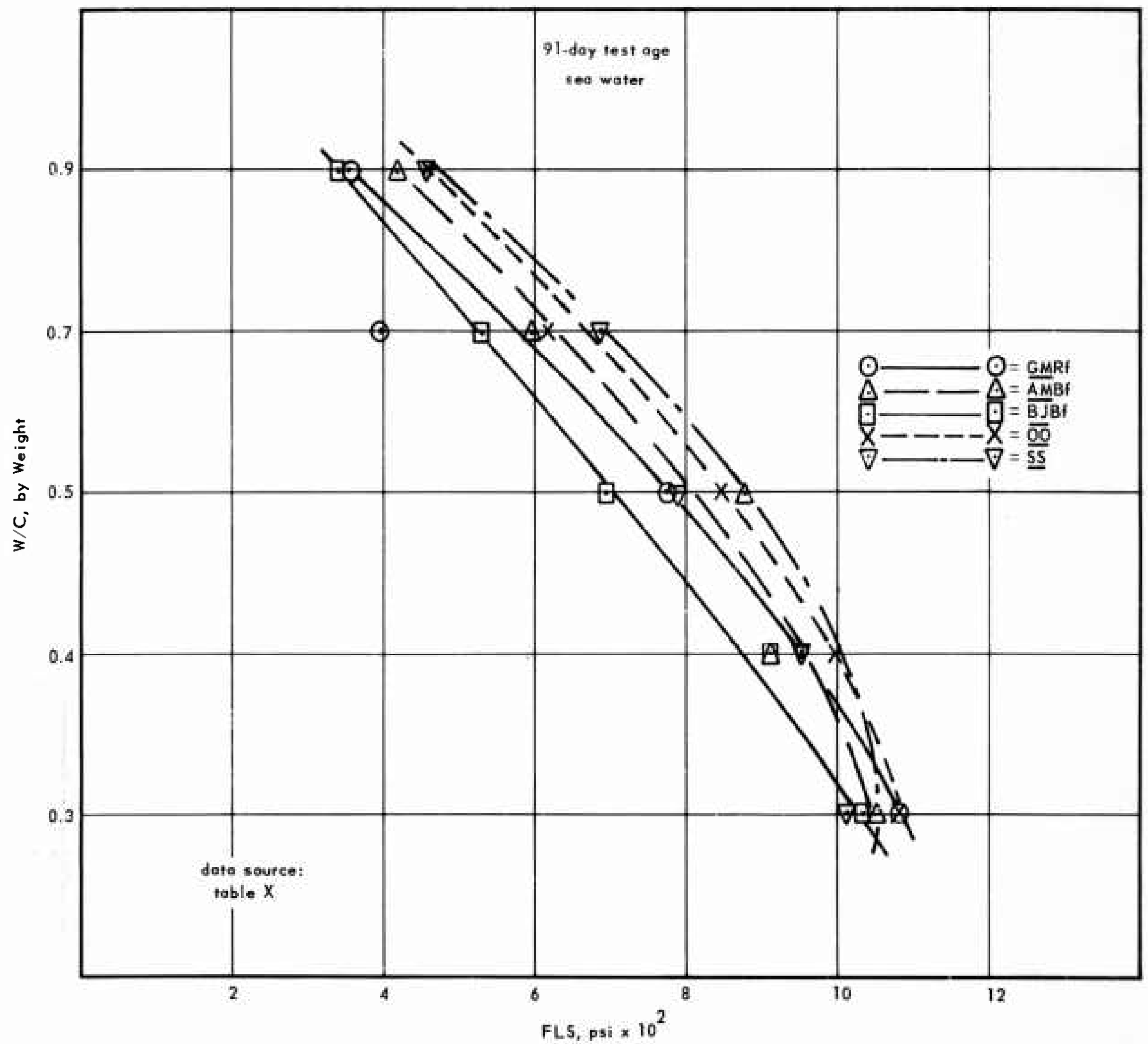

Figure 76. Correlation 8g-b'. (Part 3 of 4)

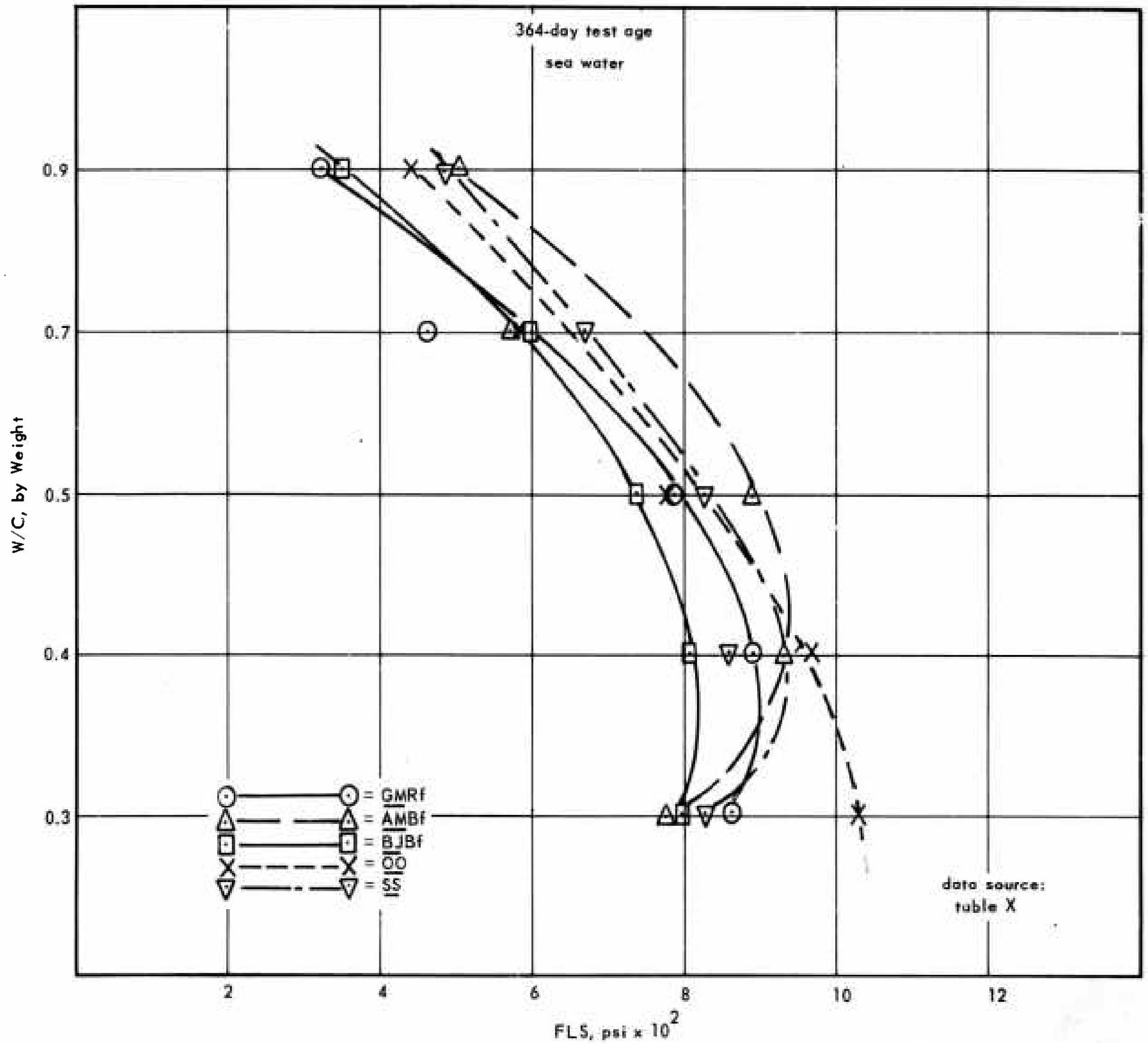

Figure 76. Correlation 8g-b'. (Part 4 of 4)

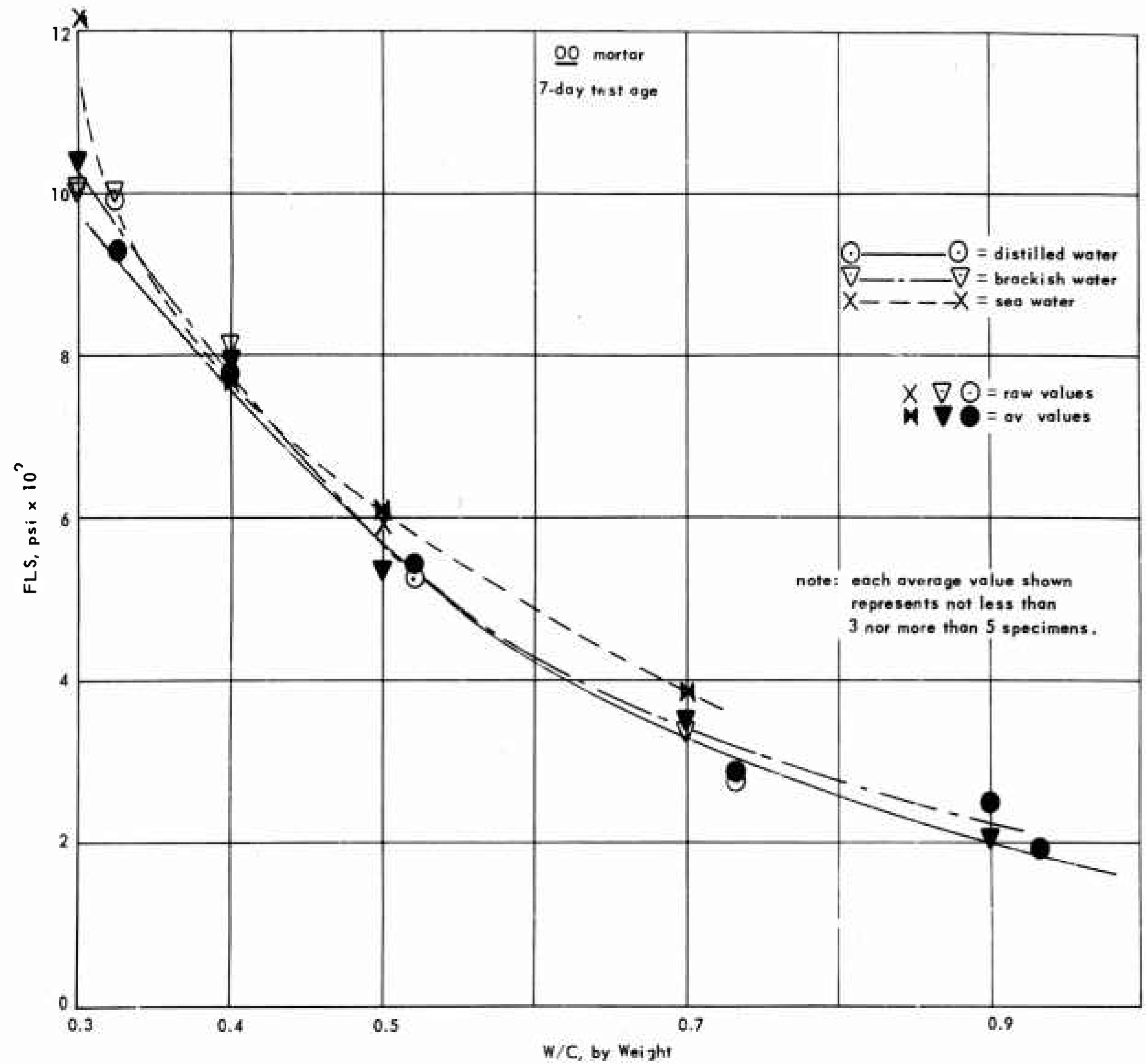

Figure 77. Correlation 8g-b'.

Correlation 8h-b'.

The variation of mortar FLS, as the A/C of the mortar mix is changed, is shown typically in Figure 78. Although the curves therein pertain to the specific conditions indicated, Figure 78 is a good general representation of this relationship and, in essence, would be very similar if the W/C values, the test age, or water type were different. This belief is based on the trends shown in Figures 79, 80, and 81, which are self-explanatory.

Correlation 8i-b'.

It is not possible to establish the influence of flow upon the FLS characteristics of the mortars. As may be seen in Figures 82, 83, and 84, at low W/C values, for any sand or water type, increase in flow is accompanied by decrease in FLS except that this trend is reversed at ages of three months or one year. At high W/C values, increased flow usually results in increased FLS except when sea water is employed, in which case no correlation whatever is possible. The validity of the curves is based on the assumptions stated in Correlation 8i-a'.

Correlation 8j-b'.

Study of Tables VII to X, inclusive, reveals that the gradual reduction of FLS with increasing EAC probably can be expressed mathematically as a hyperbolic function. This appears to be the case regardless of type of water or derivation of sand and in the case of GMRf and SS mortars regardless of whether the sand is natural- or ideal-graded. Figure 85 is typical of the variations that can be expected.

Correlation 8a-c'.

As shown in Figure 86, regardless of the water type the MCS (compressive strength of modified cubes of mortar in the solid state) increases with age; this generally is the case for all mortars tested at ages ranging from one week to one year. At early ages the use of sea water results in a slightly higher value of MCS but after age 28 days the rate of increase with age drops perceptibly so that at age one year the average MCS of sea water mortar mixes is somewhat less than that of brackish water mortars. At W/C value of 0.3, the use of sea water resulted in higher MCS values at age one year than was attained with mortars incorporating brackish water.

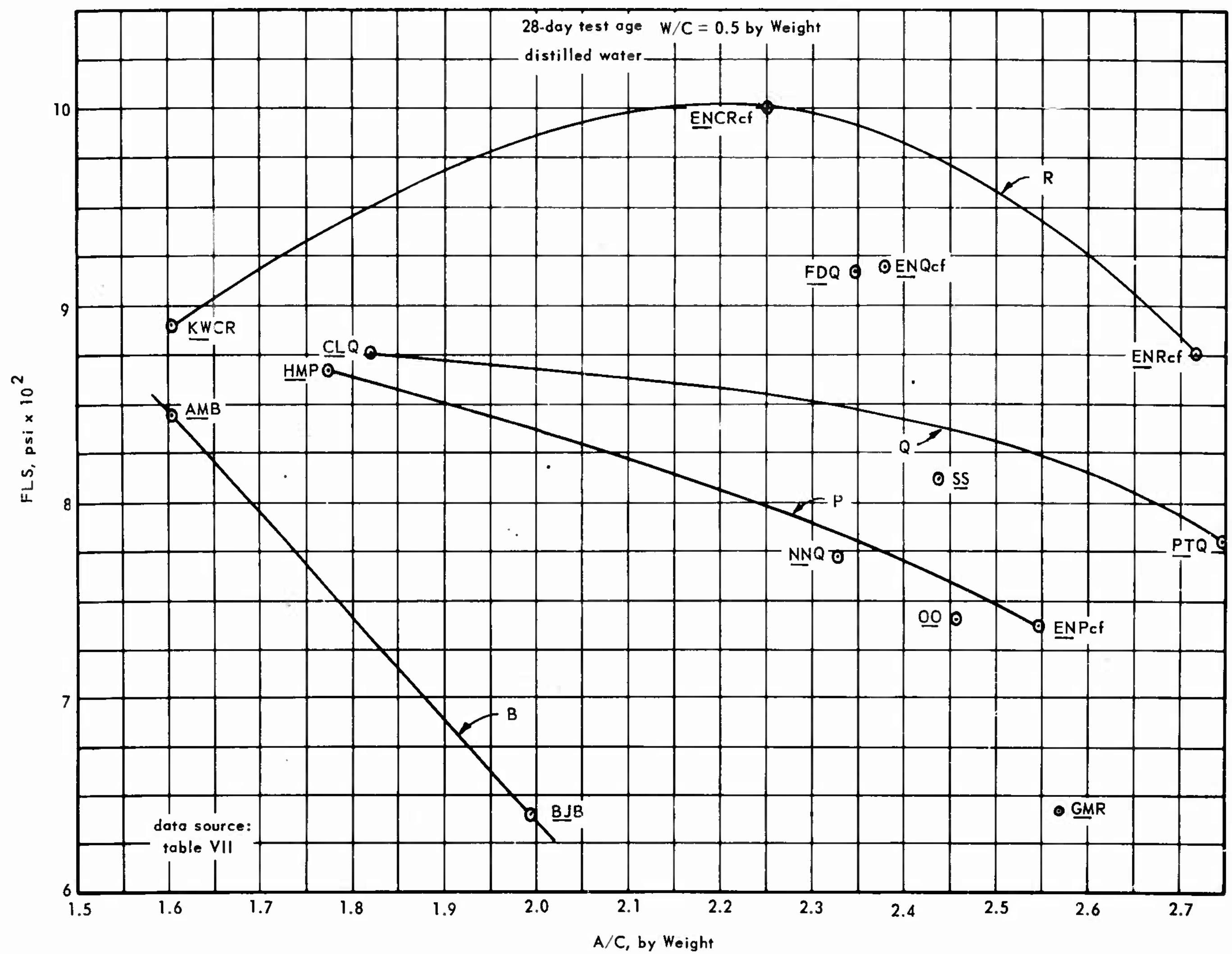

Figure 78. Correlation 8h-b'.

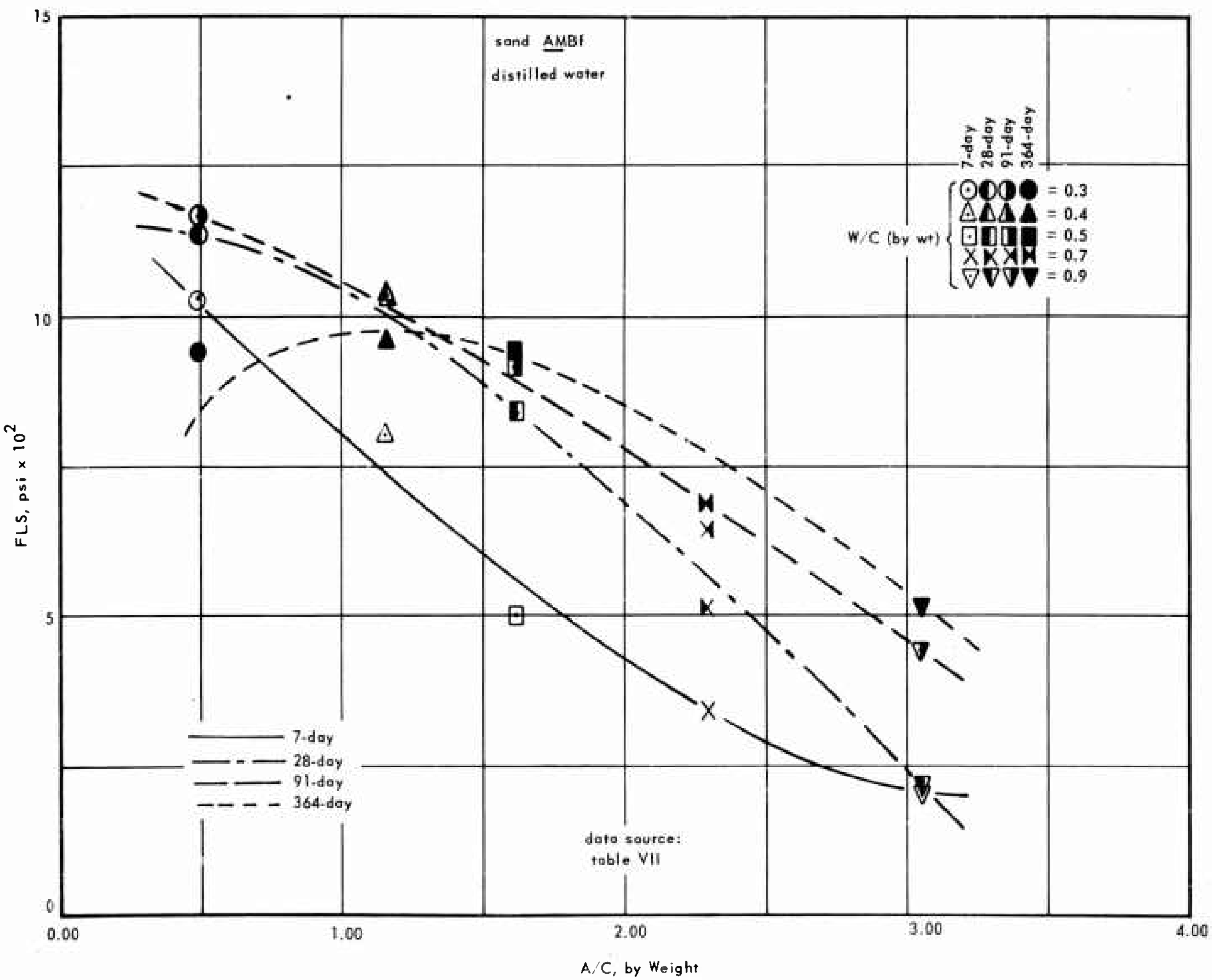

Figure 79. Correlation 8h-b'. (Part 1 of 5)

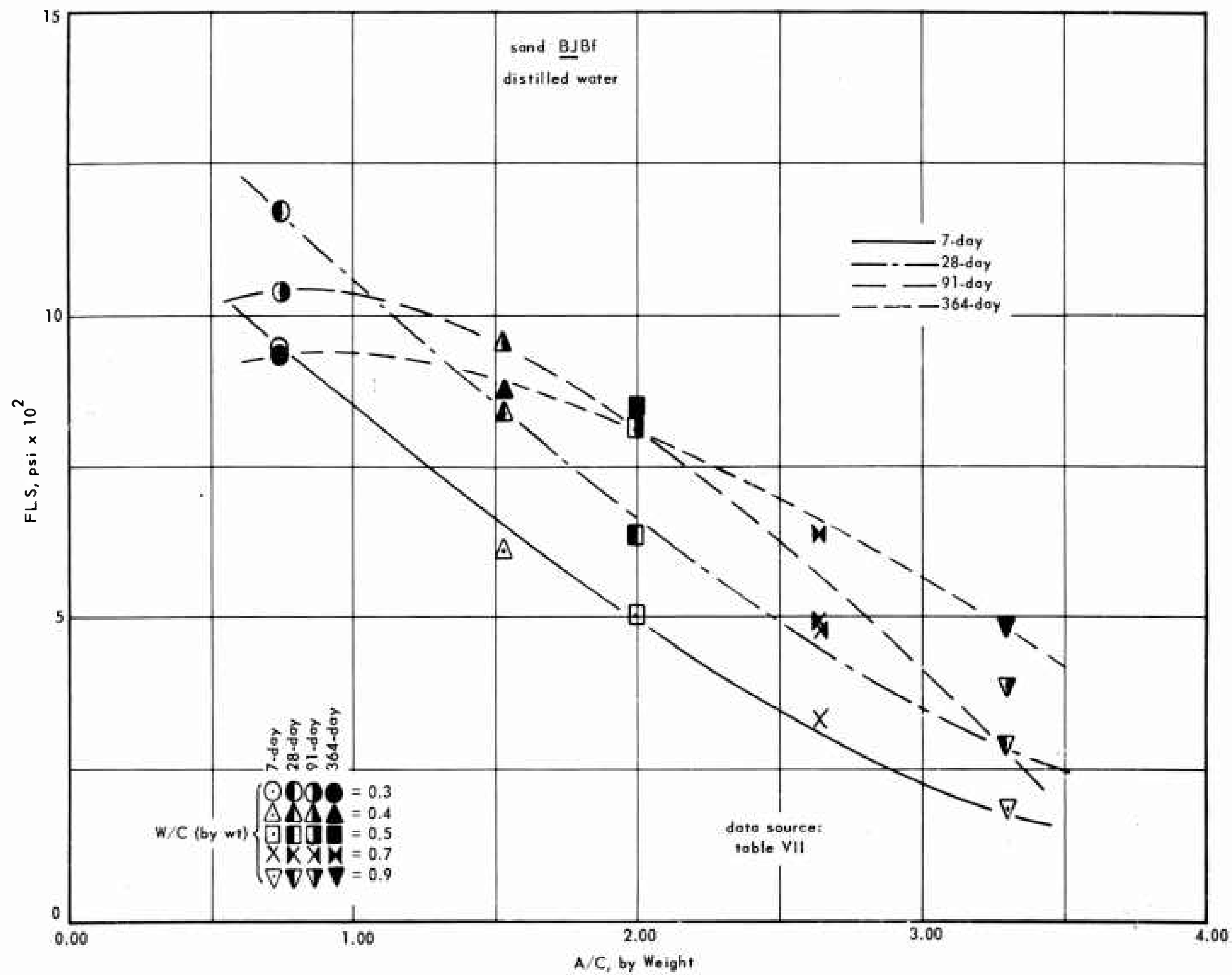

Figure 79. Correlation 8h-b'. (Part 2 of 5)

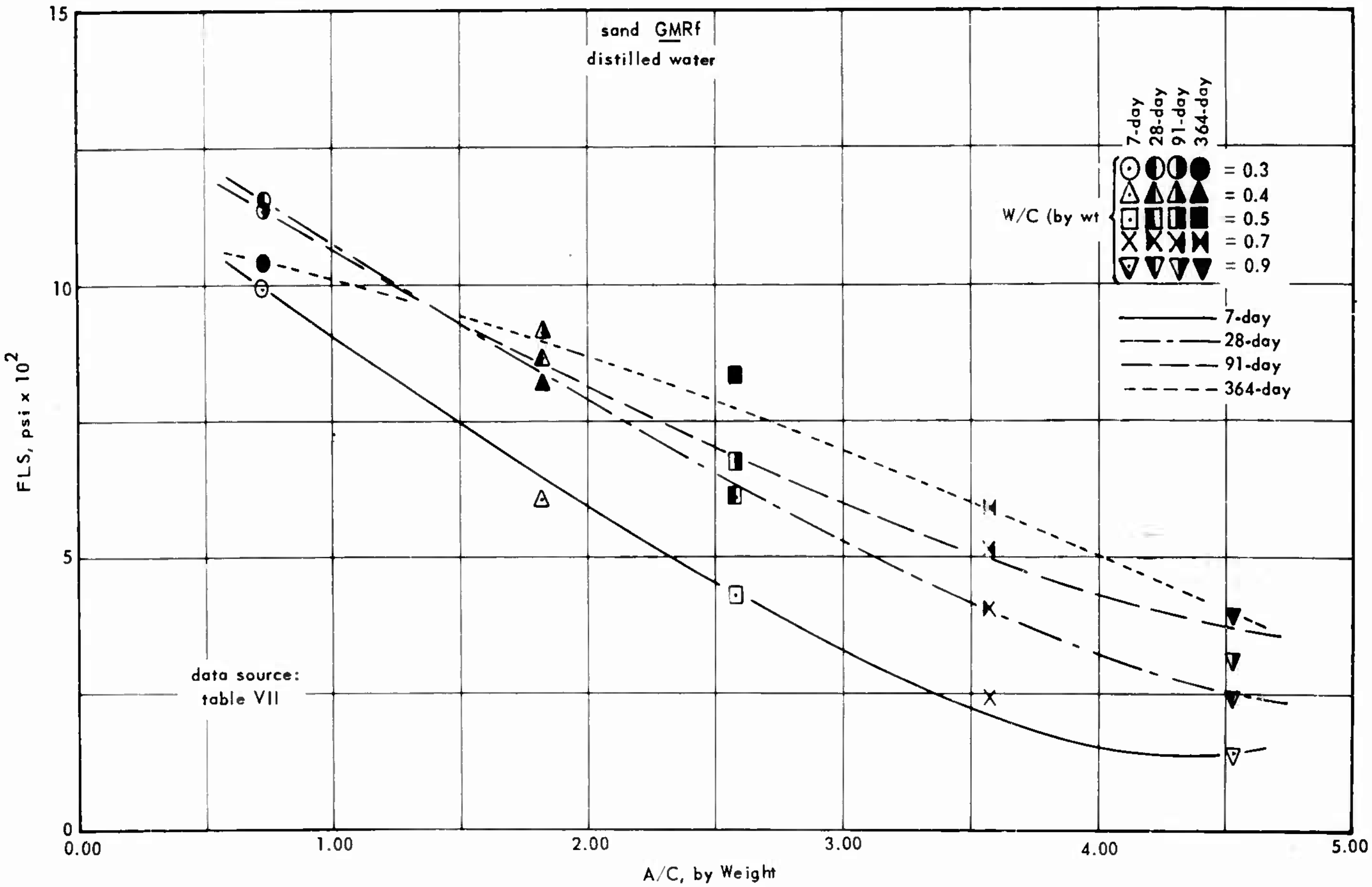

Figure 79. Correlation 8h-b'. (Part 3 of 5)

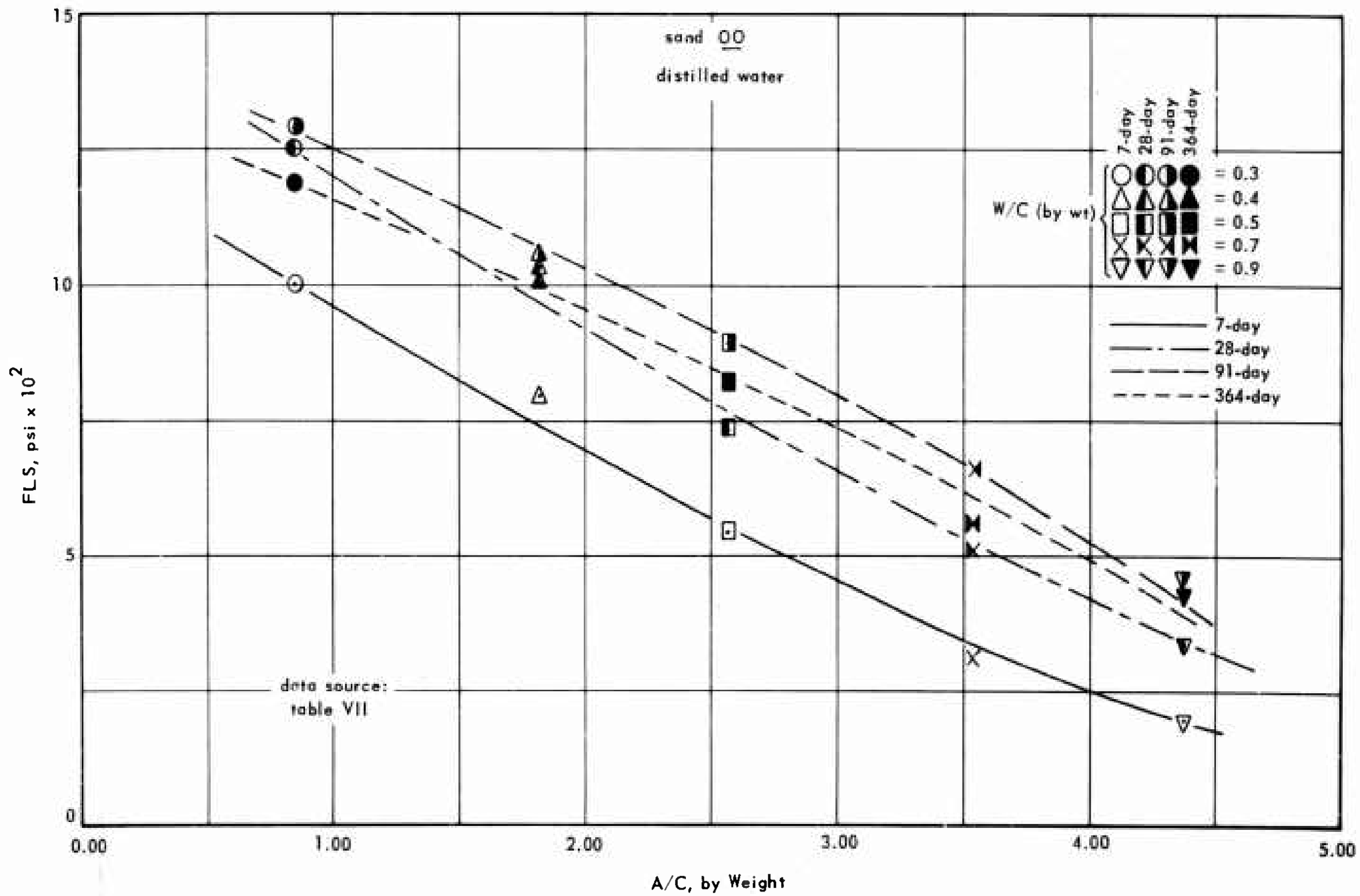

Figure 79. Correlation 8h-b'. (Part 4 of 5)

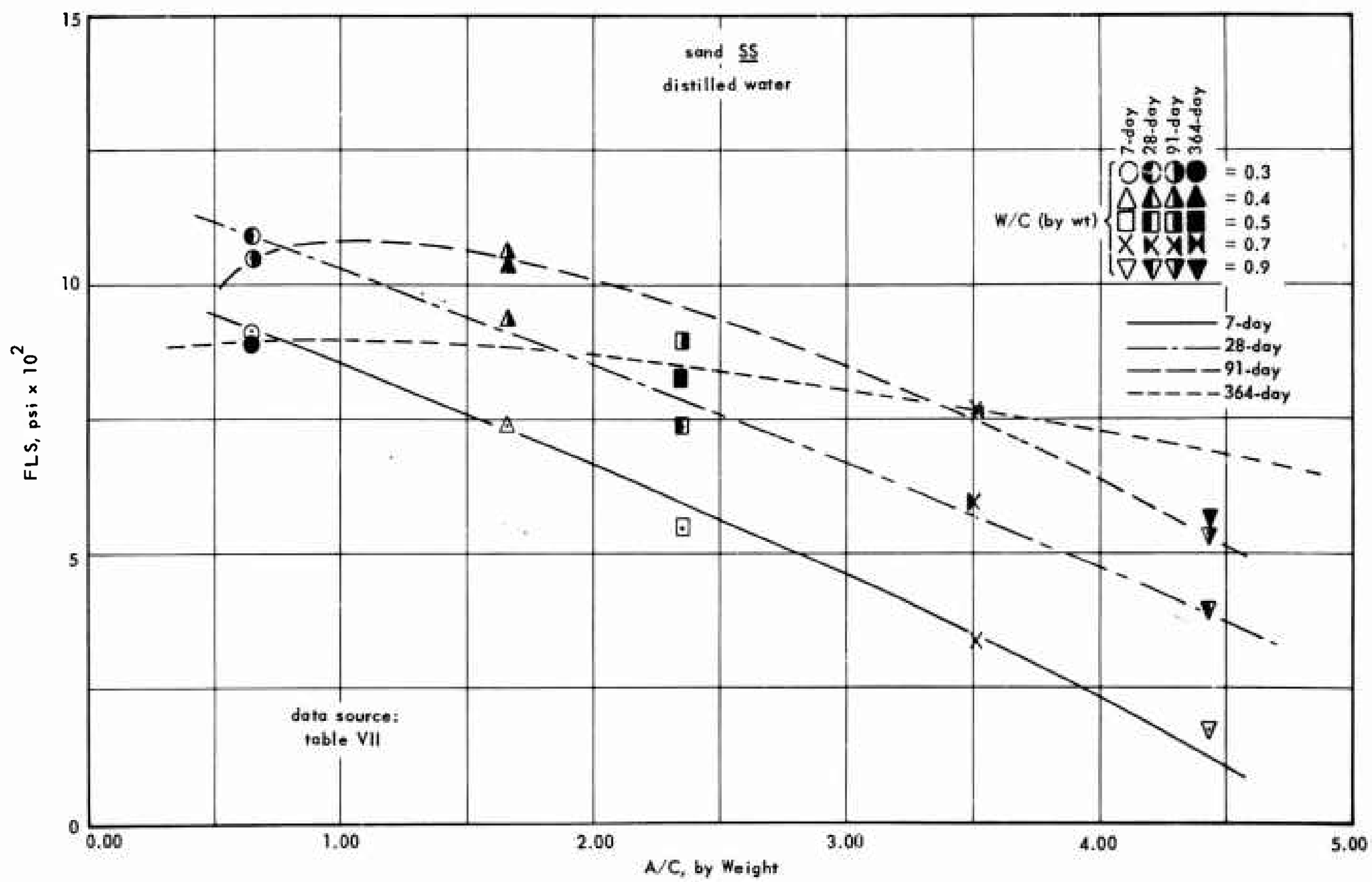

Figure 79. Correlation 8h-b'. (Part 5 of 5)

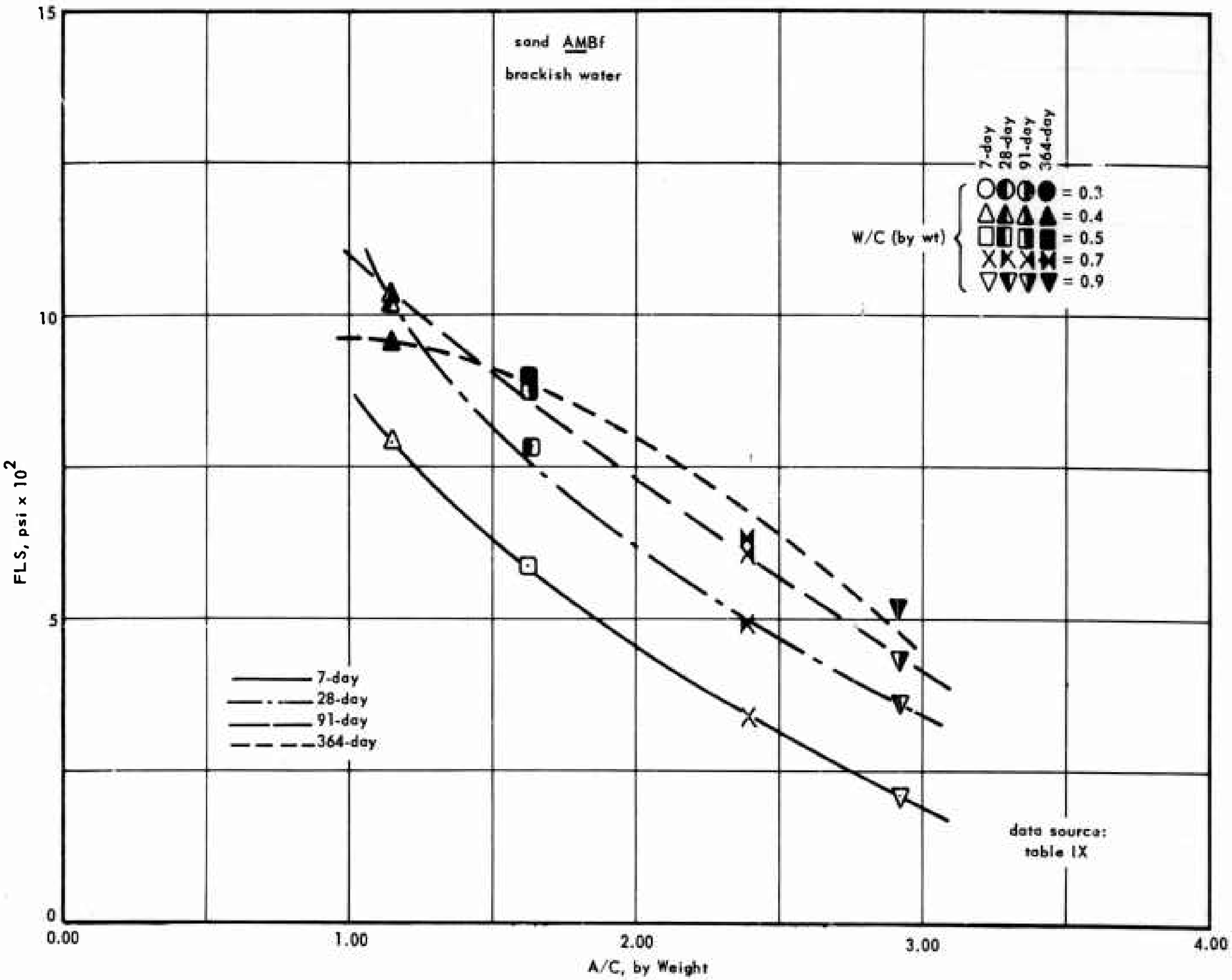

Figure 80. Correlation 8h-b'. (Part 1 of 5)

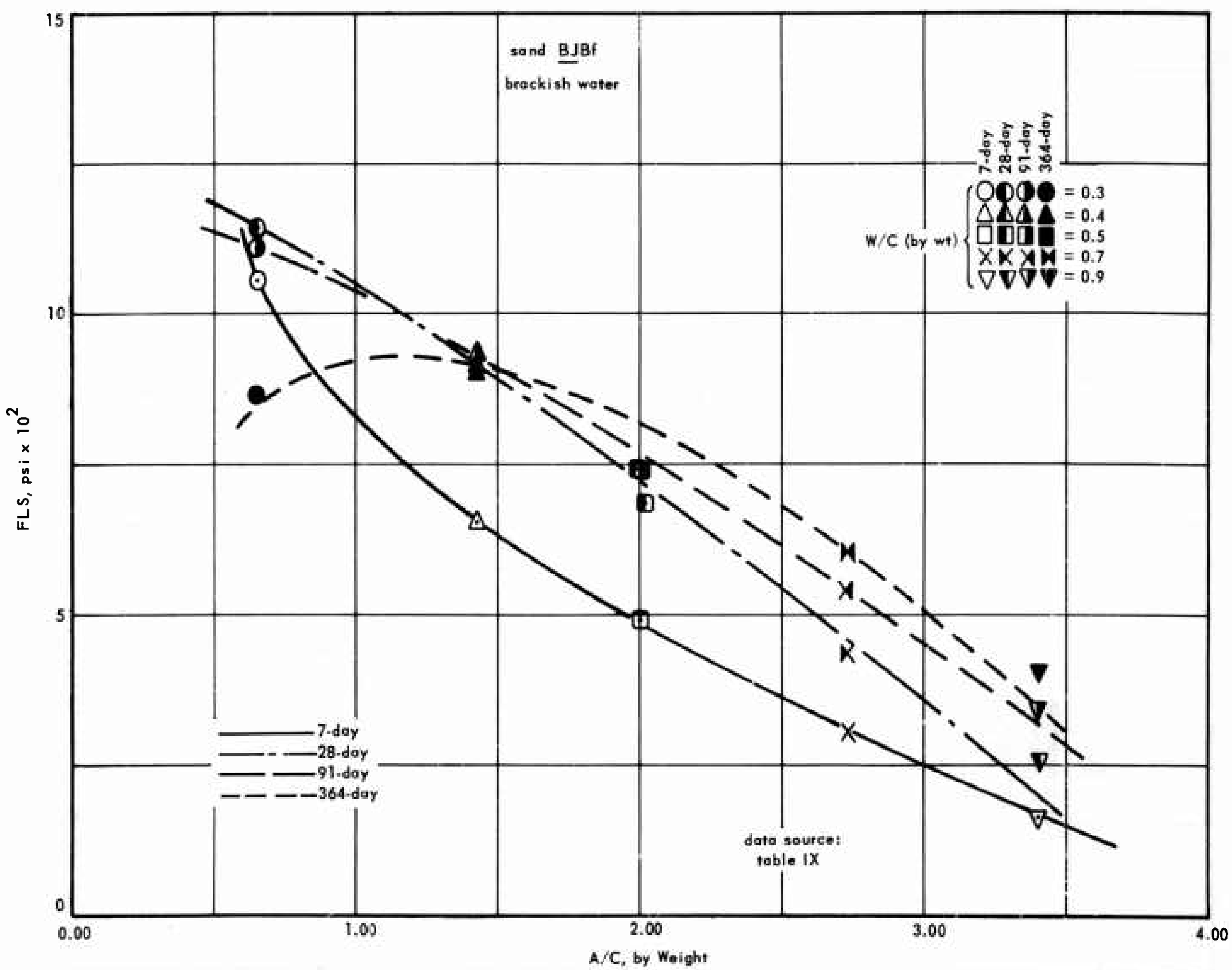

Figure 80. Correlation 8h-b'. (Part 2 of 5)

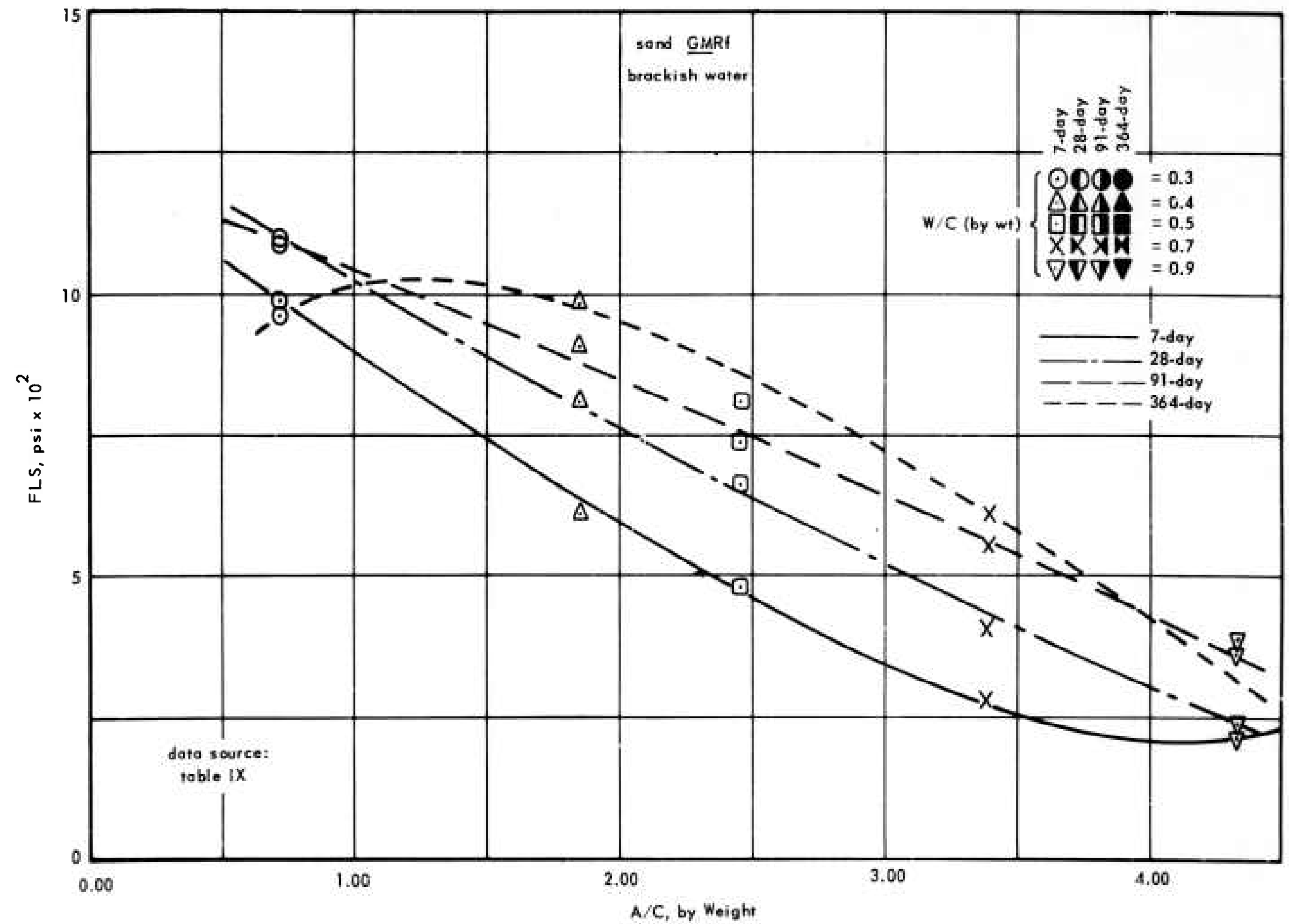

Figure 80. Correlation 8h-b'. (Part 3 of 5)

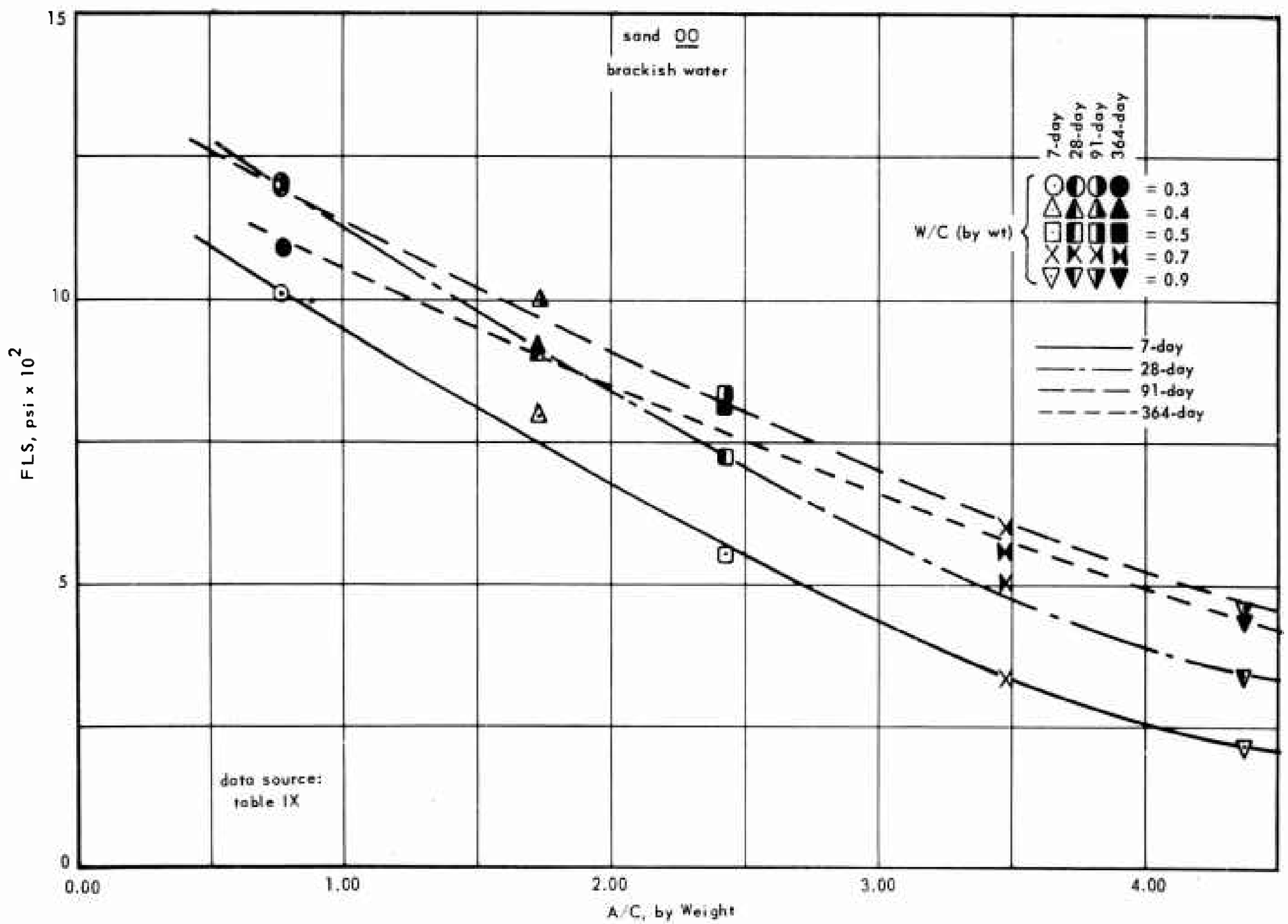

Figure 80. Correlation 8h-b'. (Part 4 of 5)

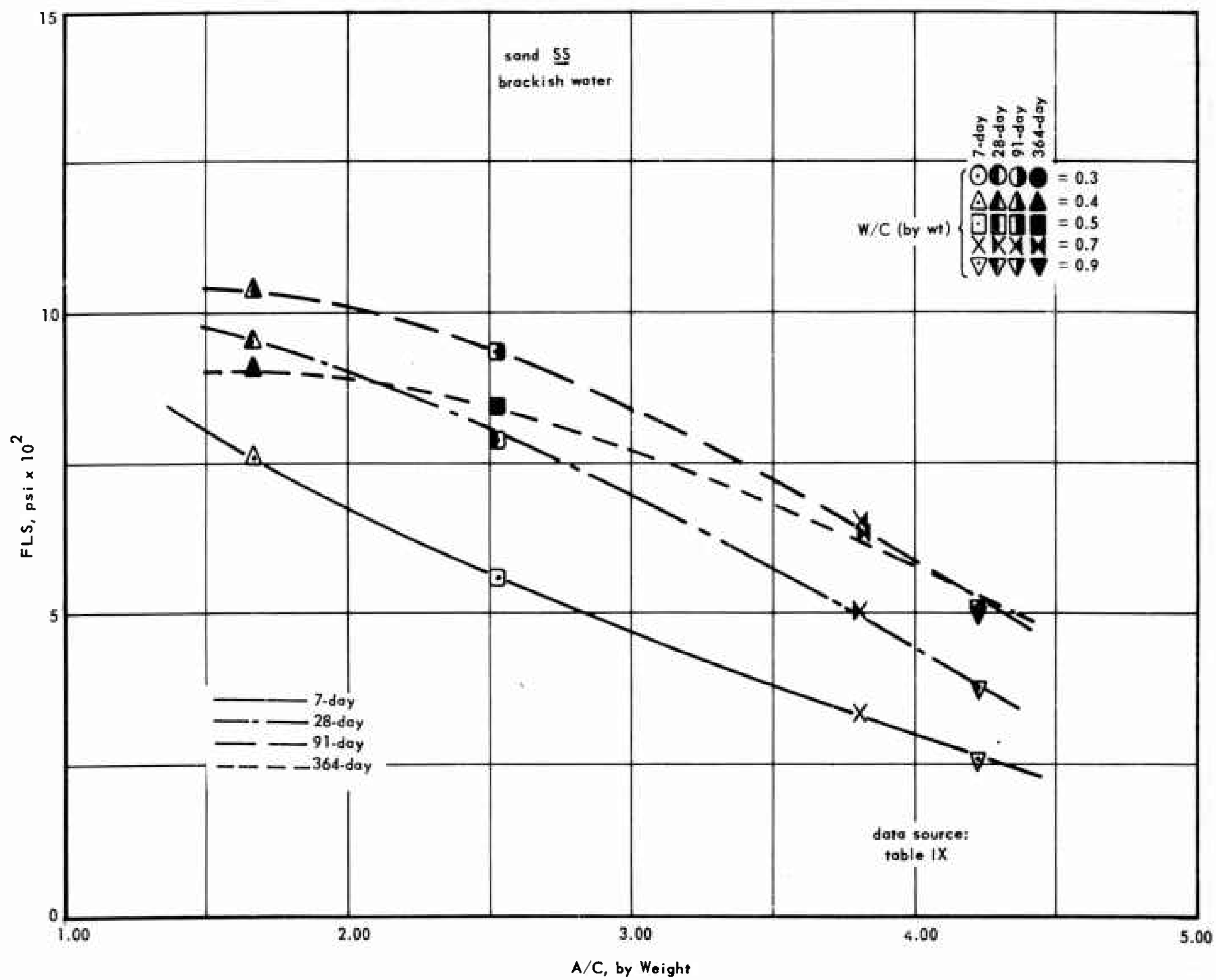

Figure 80. Correlation 8h-b'. (Part 5 of 5)

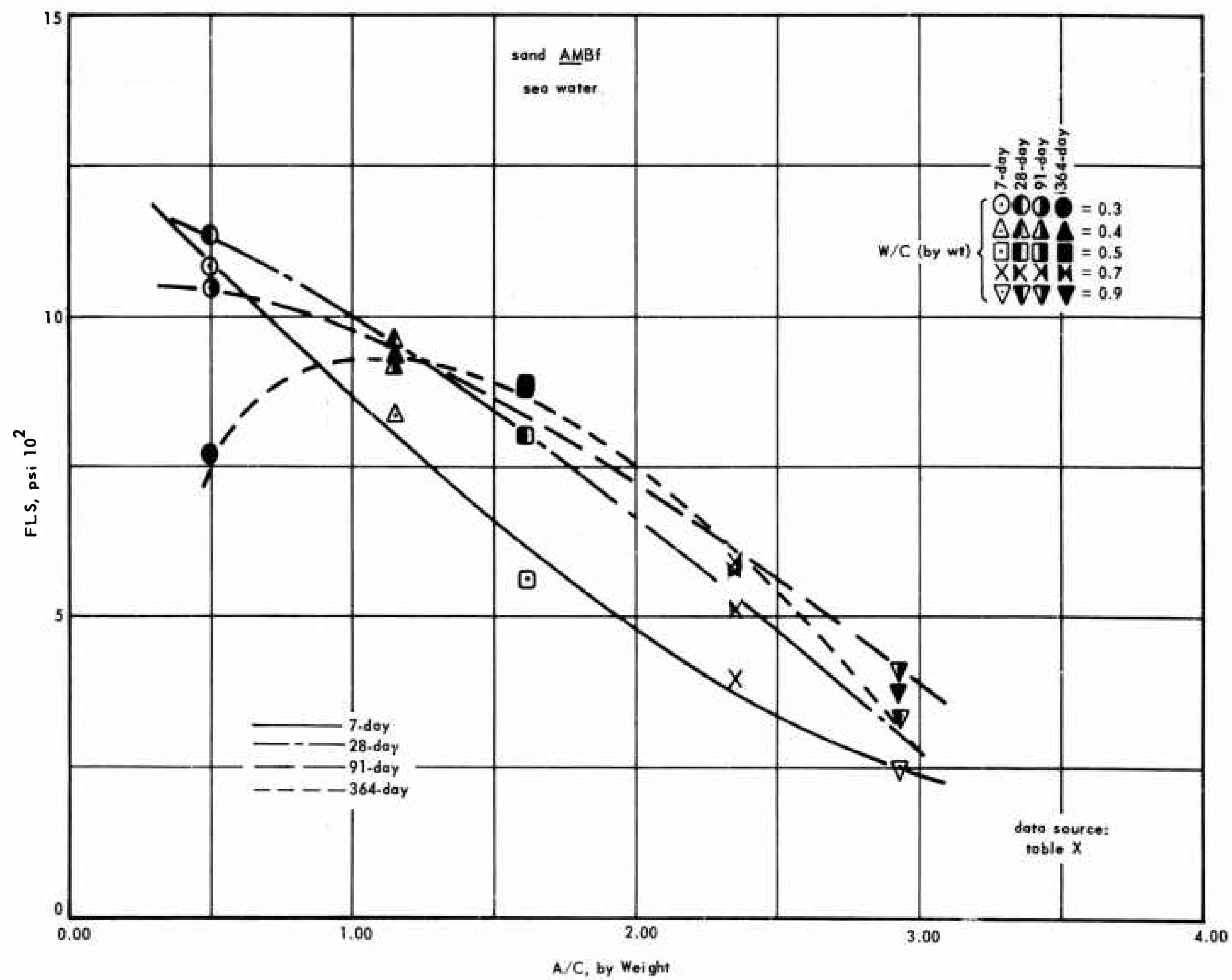

Figure 81. Correlation 8h-b'. (Part 1 of 5)

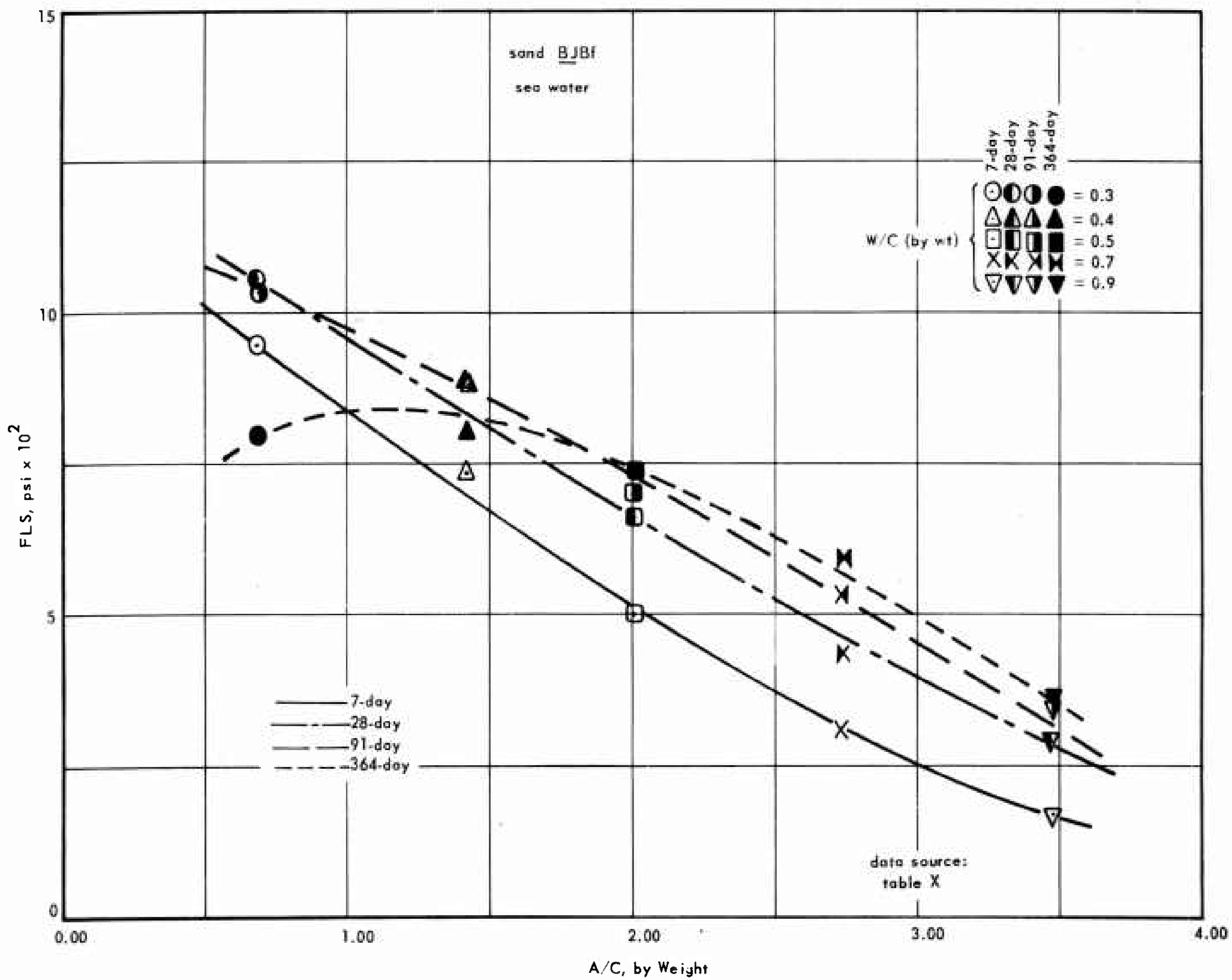

Figure 81. Correlation 8h-b'. (Part 2 of 5)

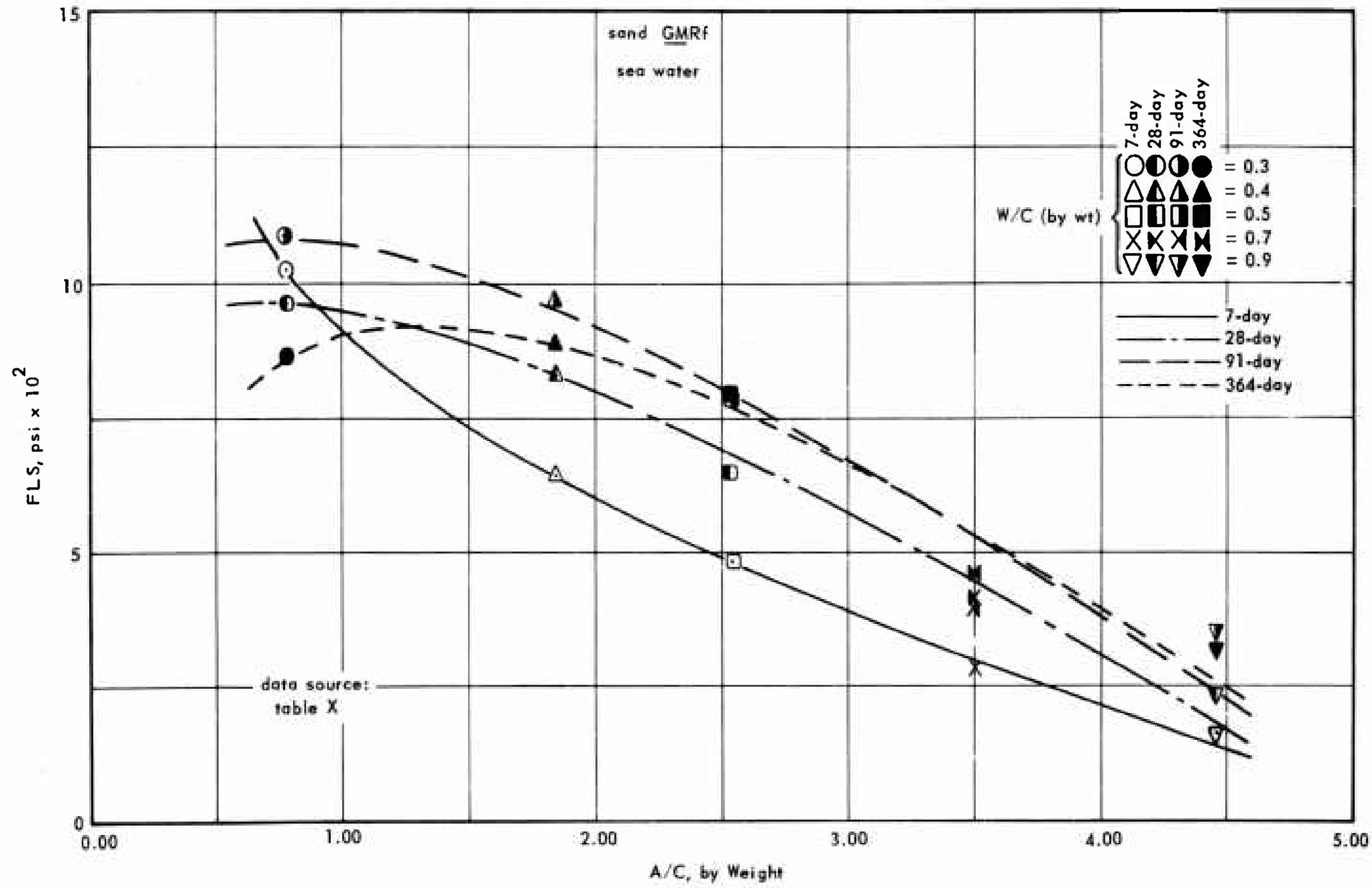

Figure 81. Correlation 8h-b'. (Part 3 of 5)

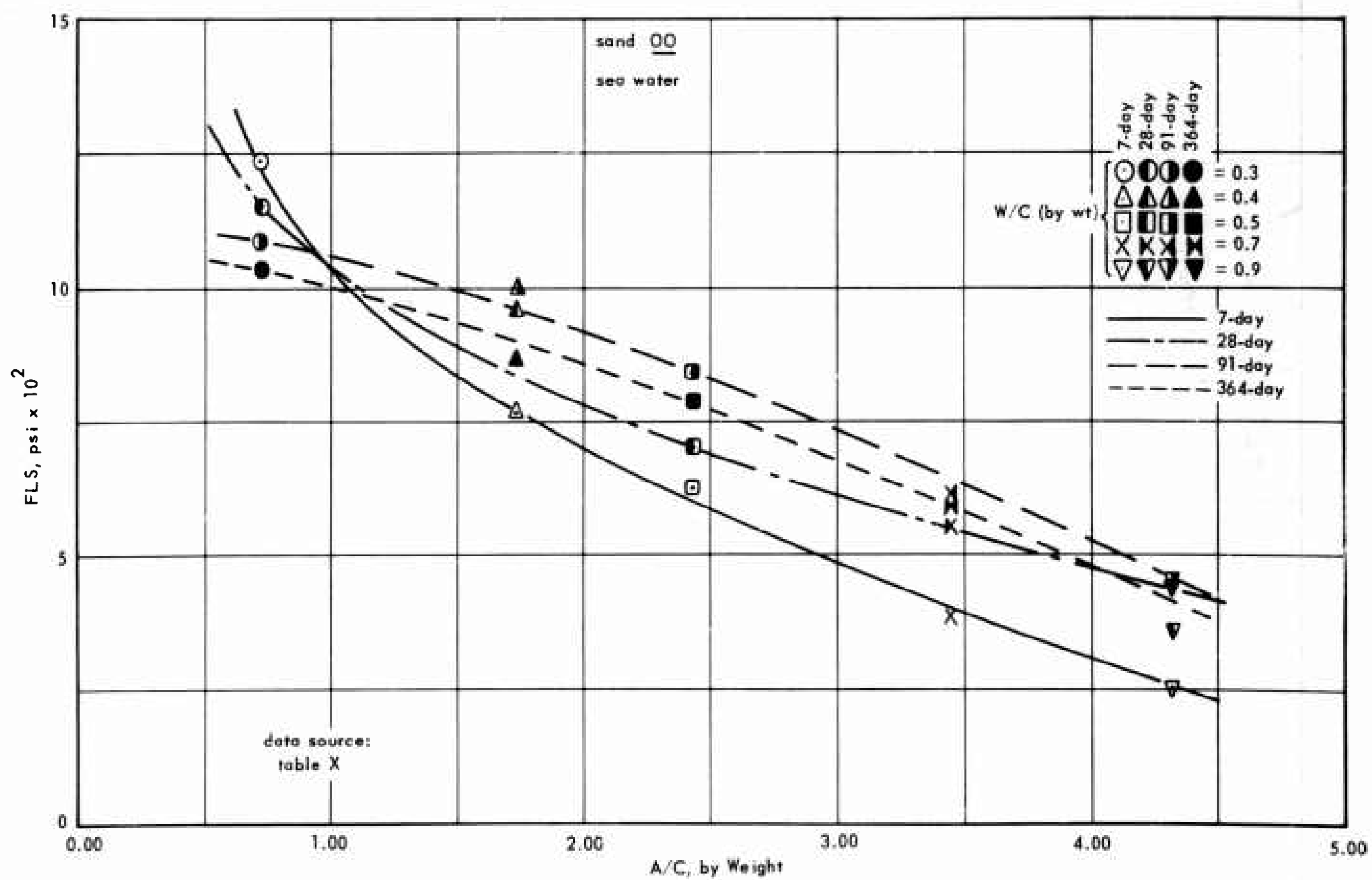

Figure 81. Correlation 8h-b'. (Part 4 of 5)

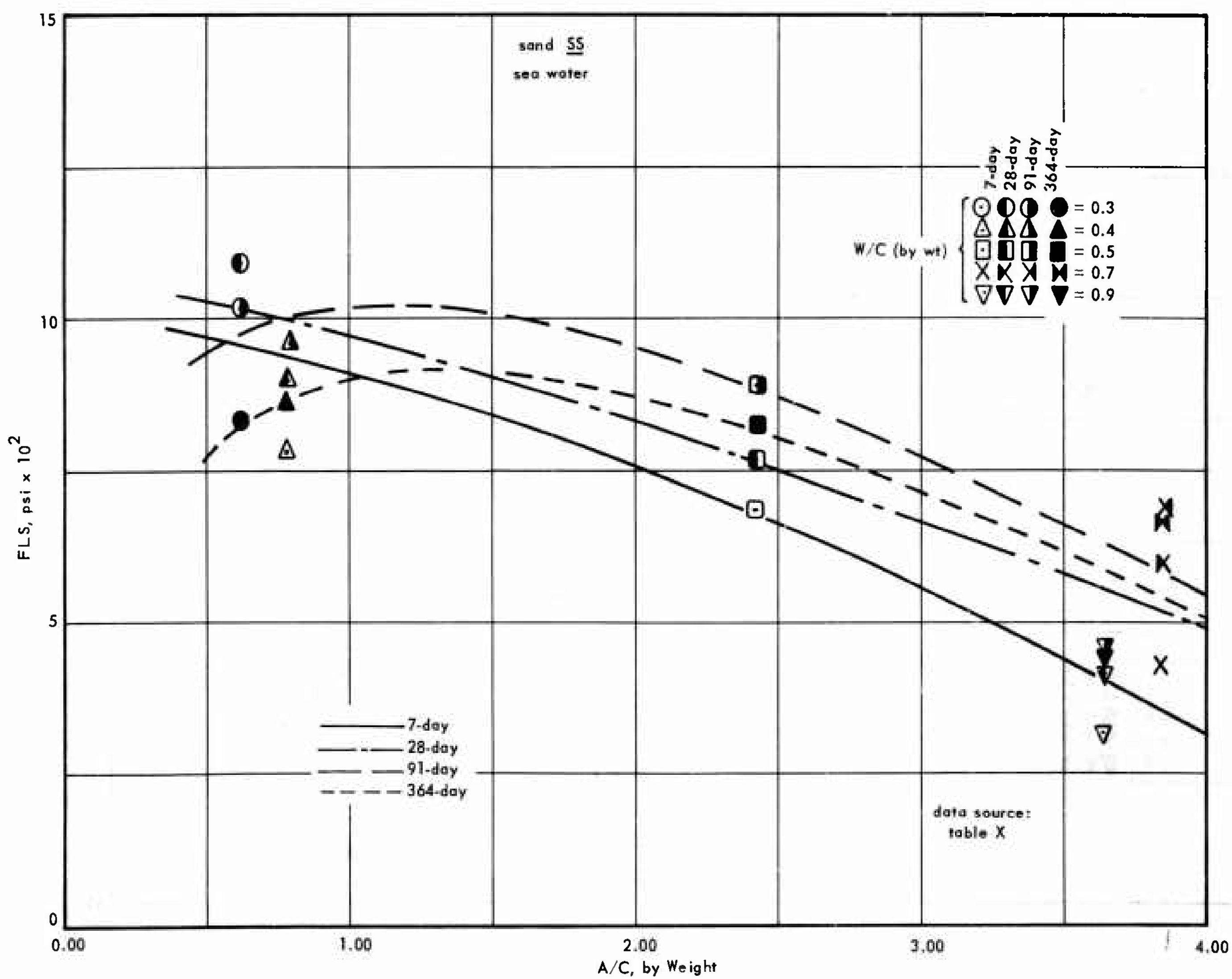

Figure 81. Correlation 8h-b'. (Part 5 of 5)

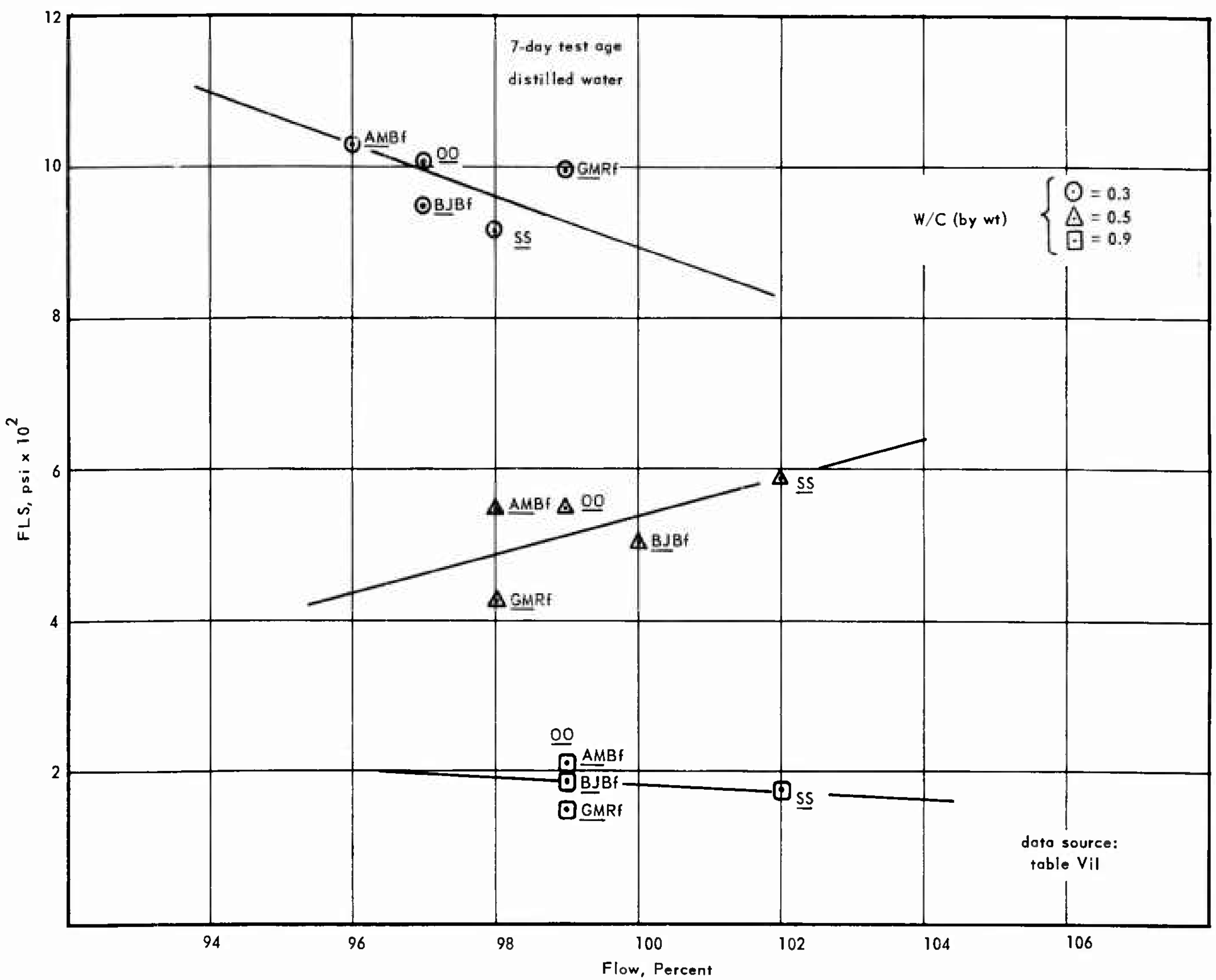

Figure 82. Correlation 8i-b'. (Part 1 of 4)

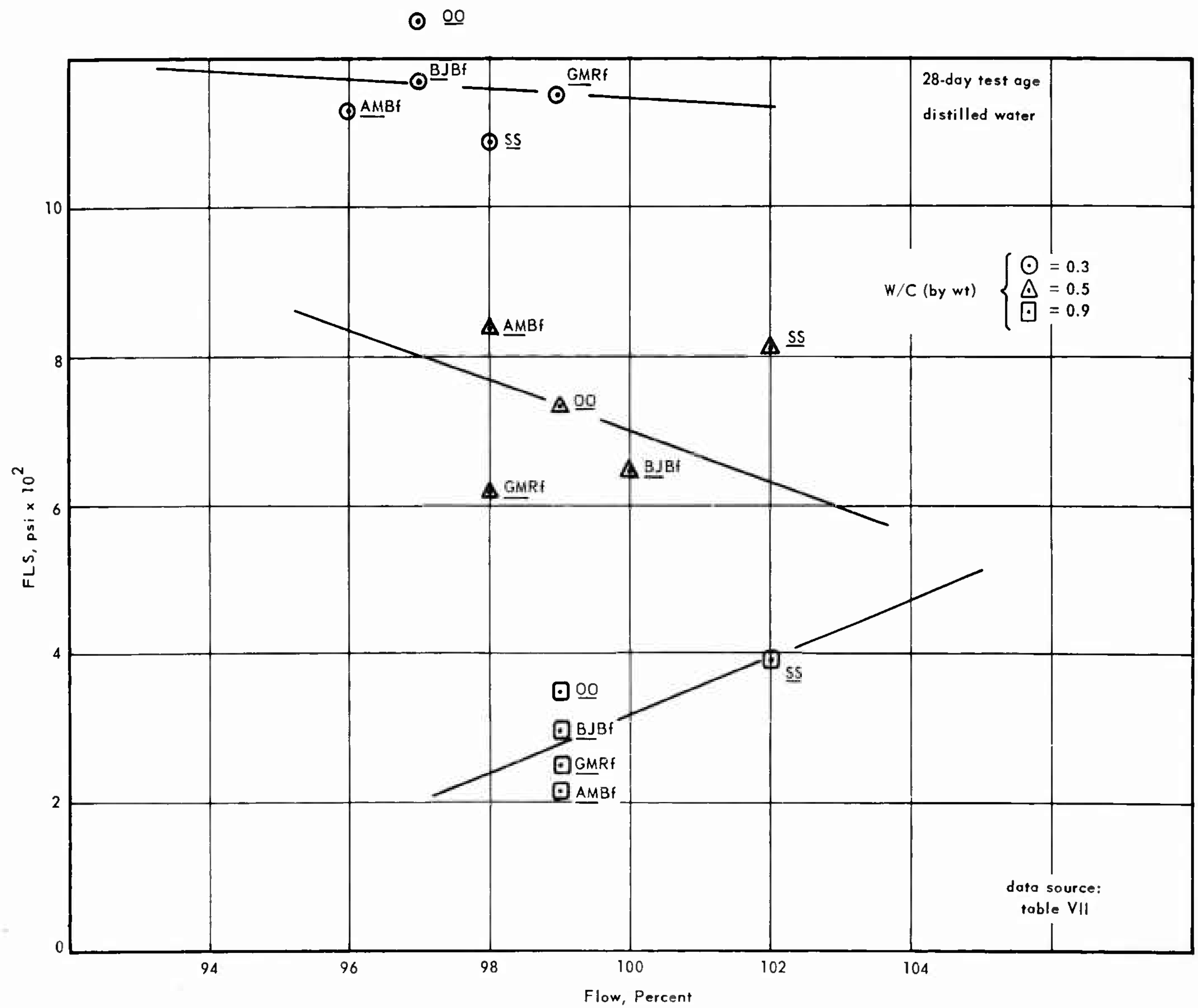

Figure 82. Correlation 8i-b'. (Part 2 of 4)

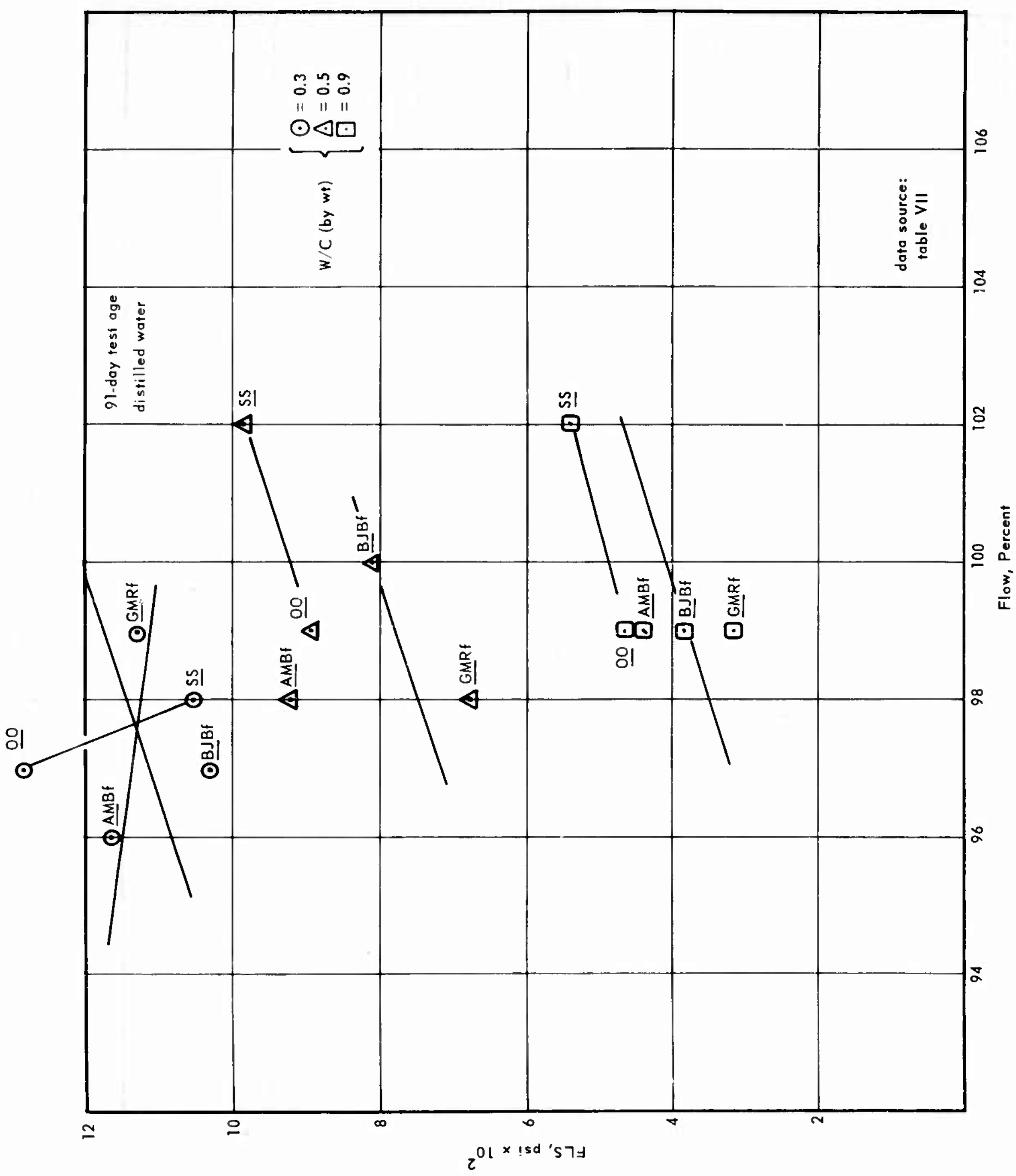

Figure 82. Correlation 8i-b'. (Part 3 of 4)

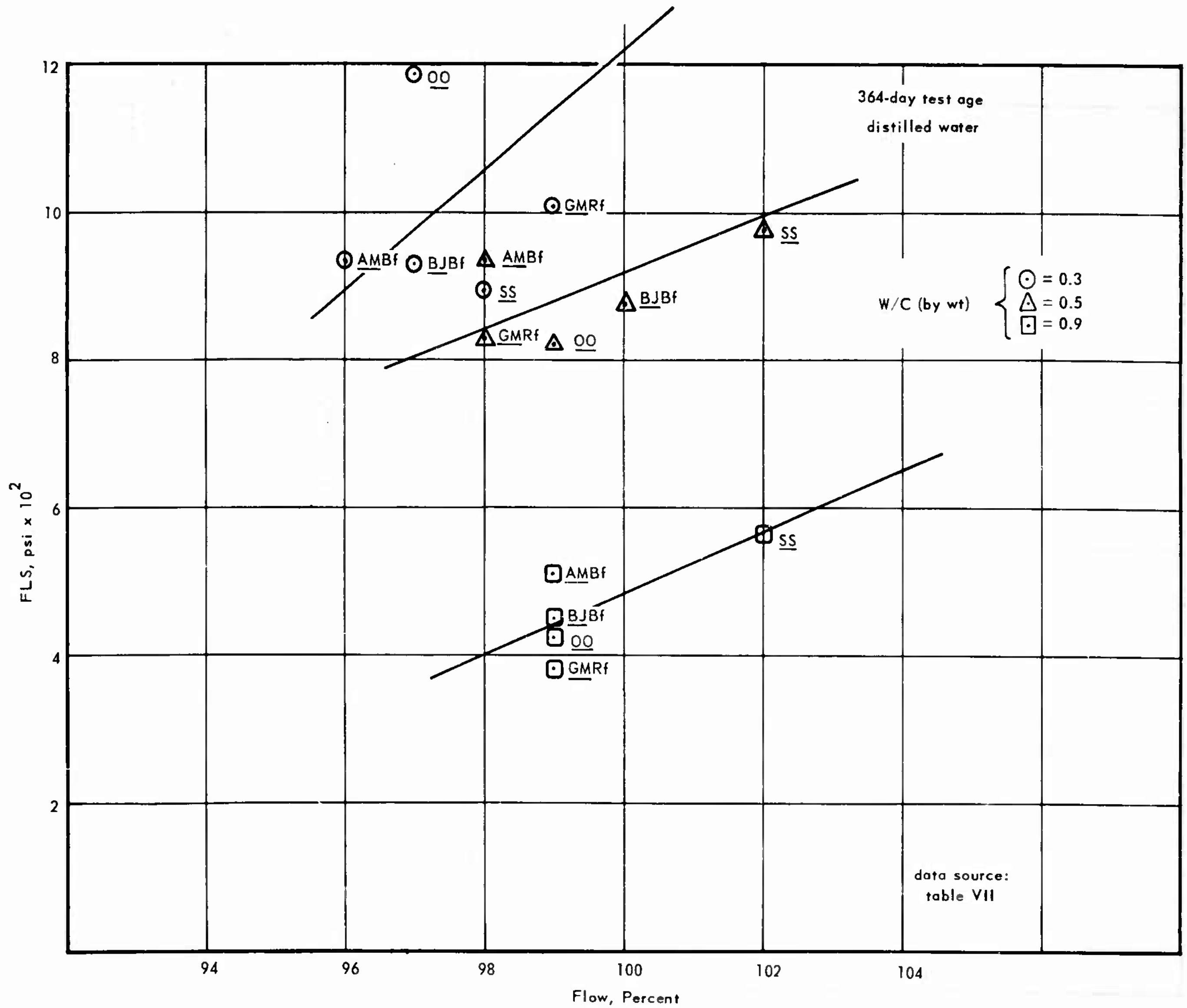

Figure 82. Correlation 8i-b'. (Part 4 of 4)

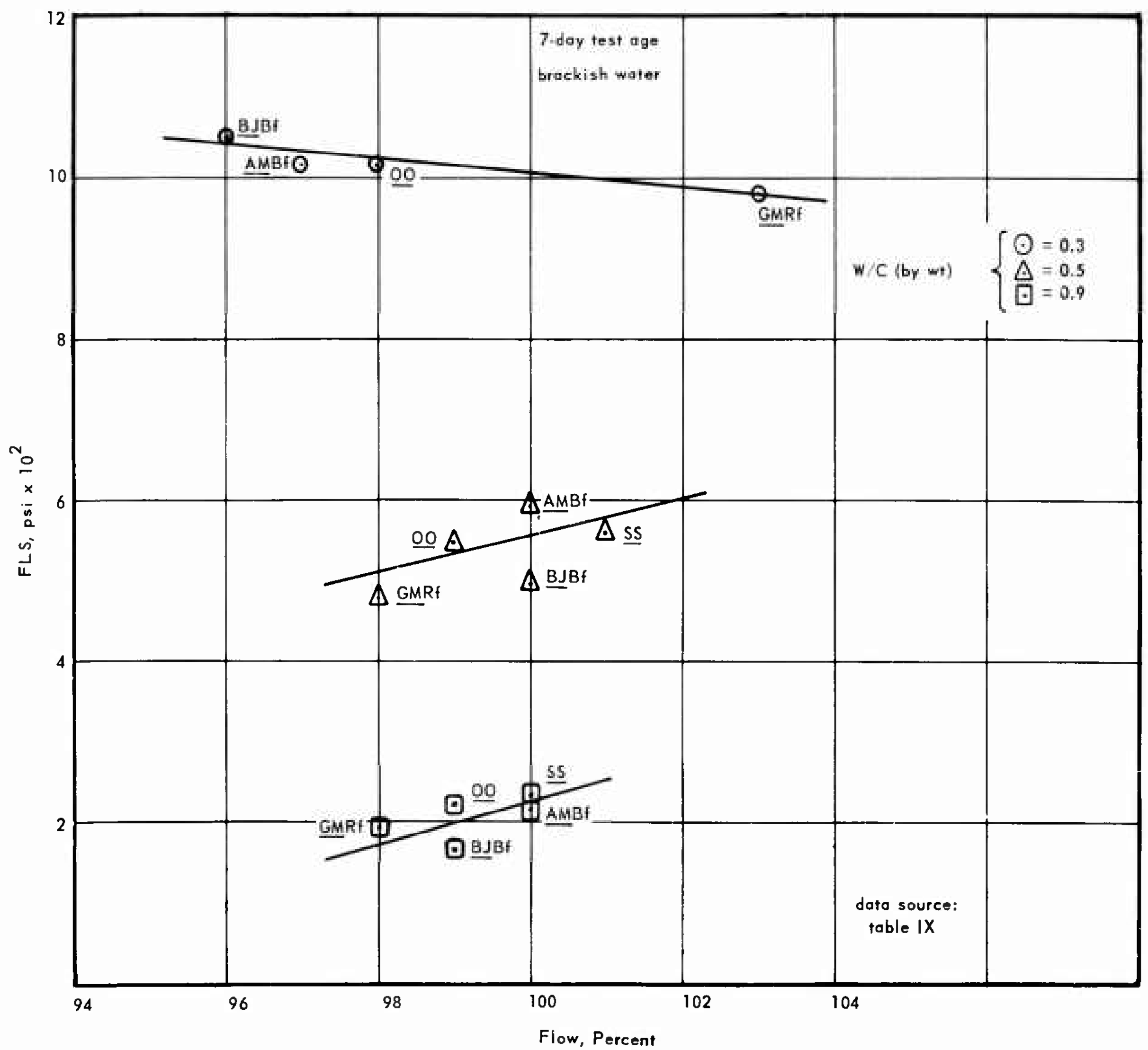

Figure 83. Correlation 8i-b'. (Part 1 of 4)

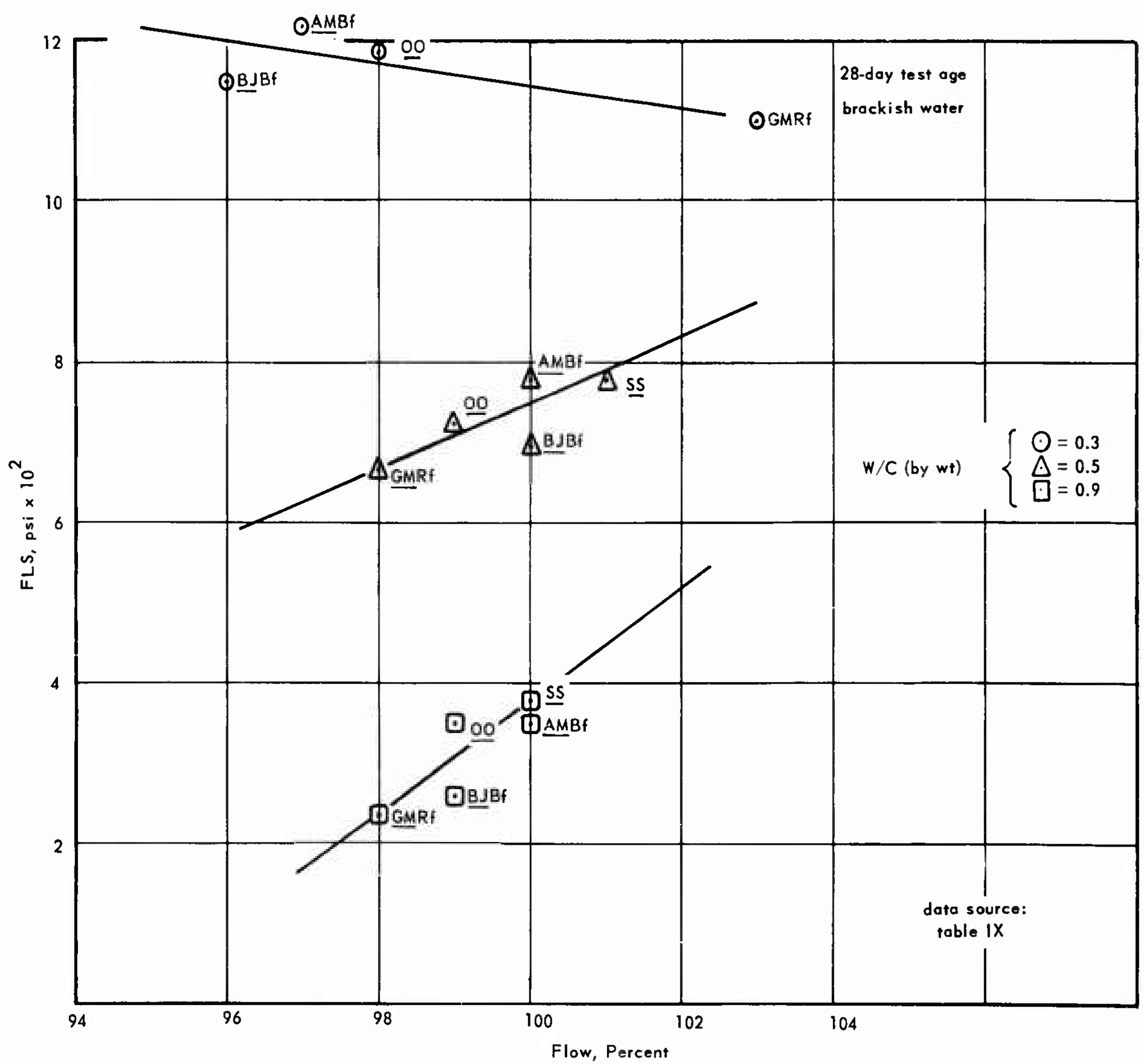

Figure 83. Correlation 8i-b'. (Part 2 of 4)

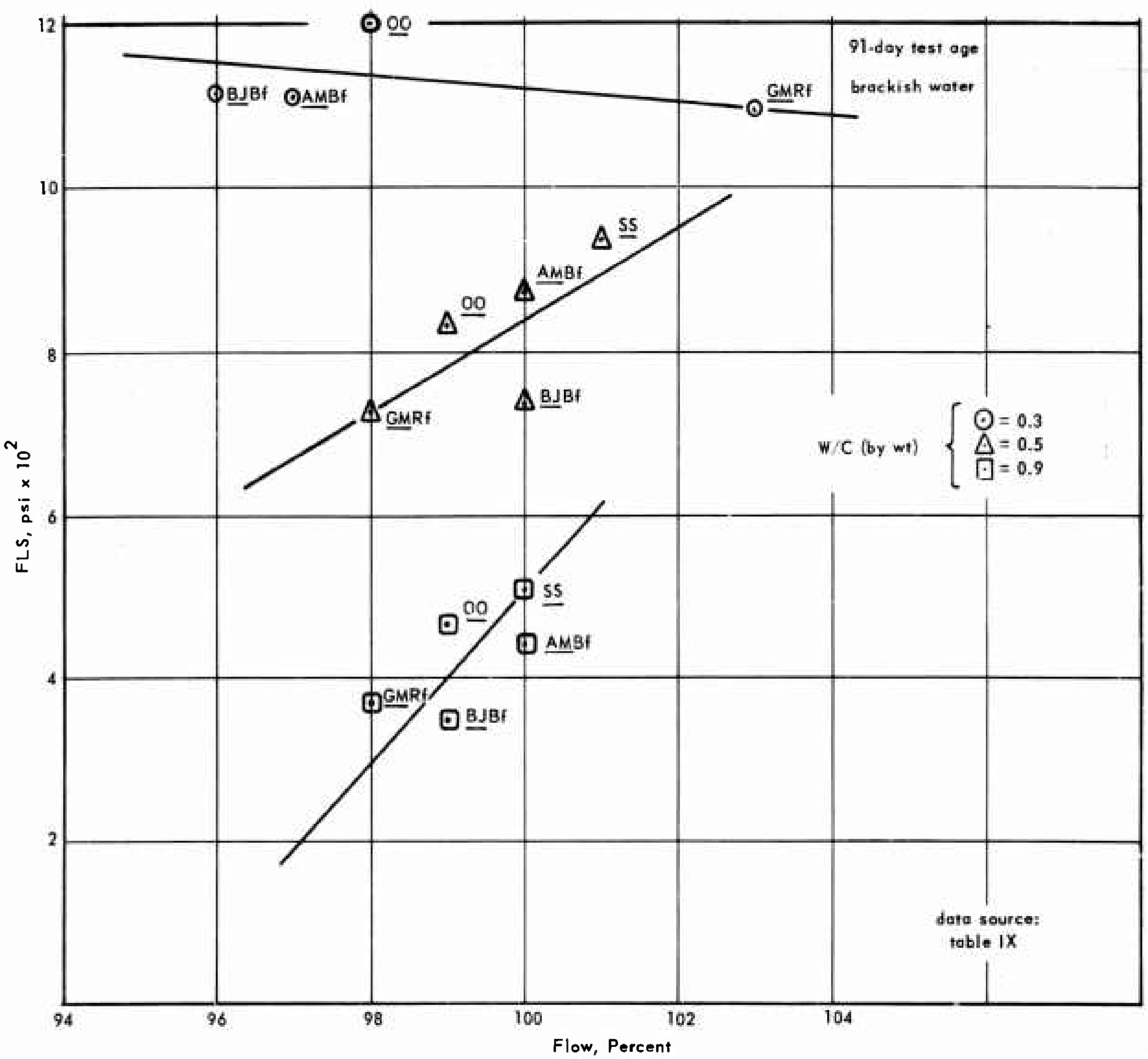

Figure 83. Correlation 8i-b'. (Part 3 of 4)

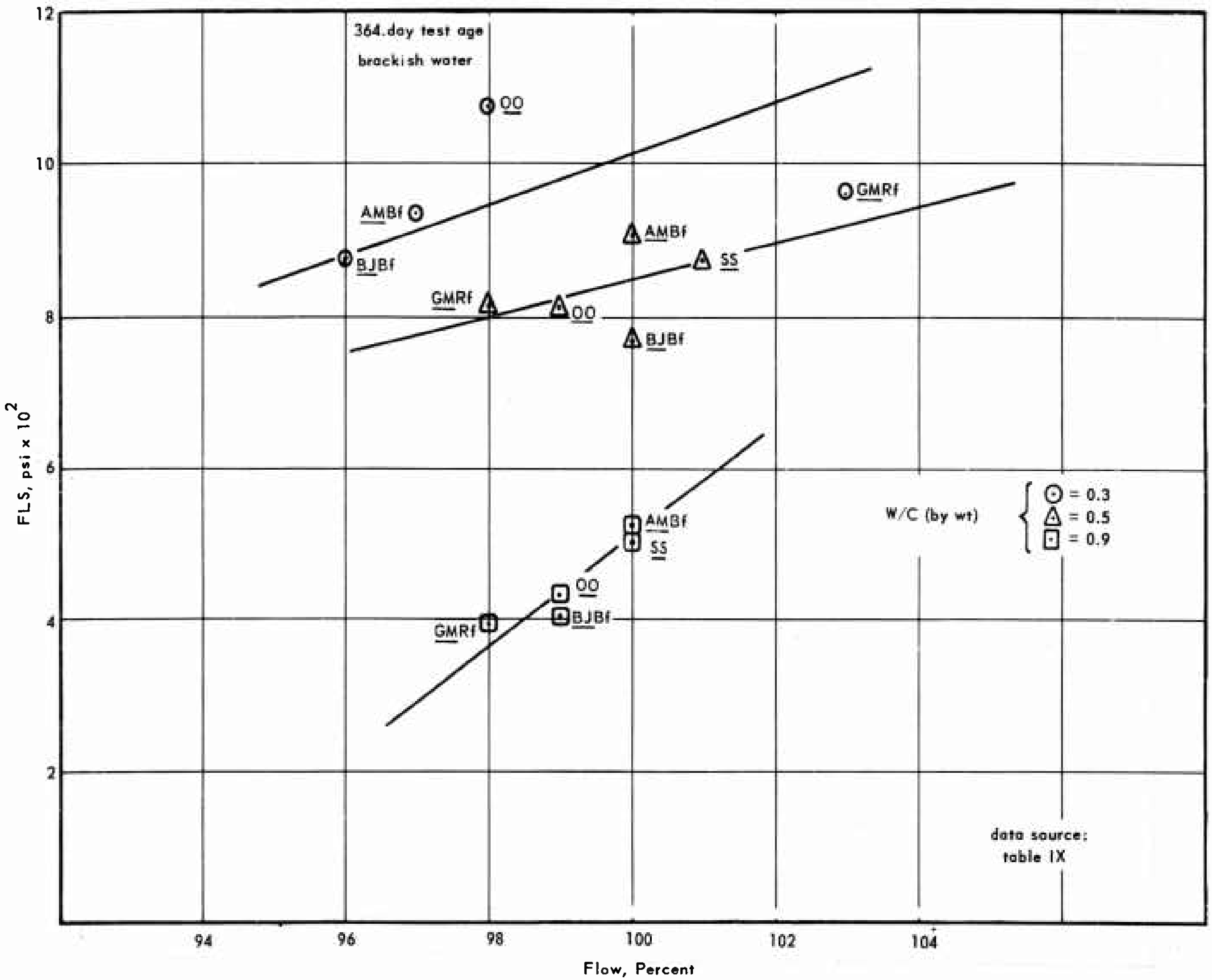

Figure 83. Correlation 8i-b'. (Part 4 of 4)

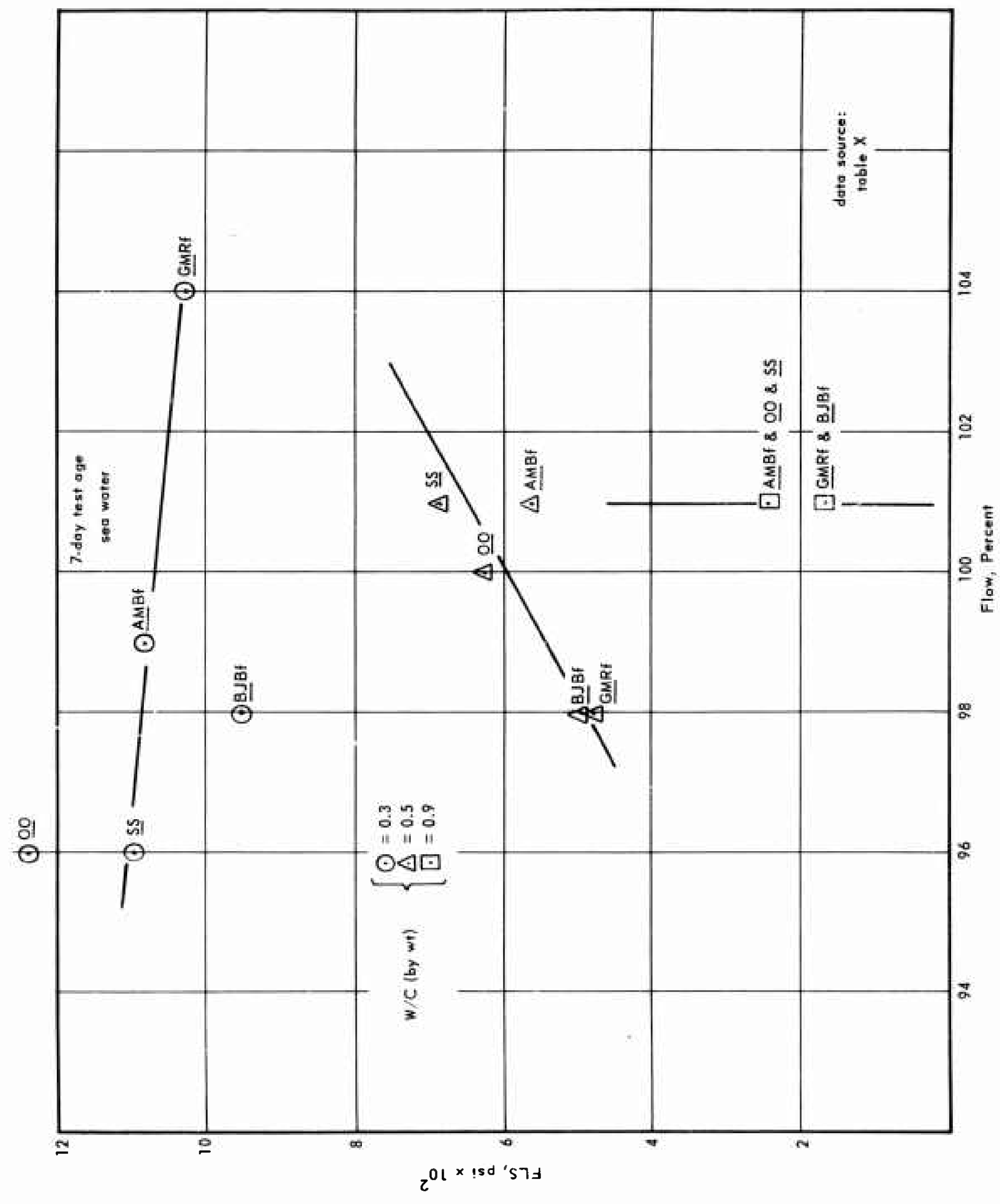

Figure 84. Correlation 8i-b'. (Part 1 of 4)

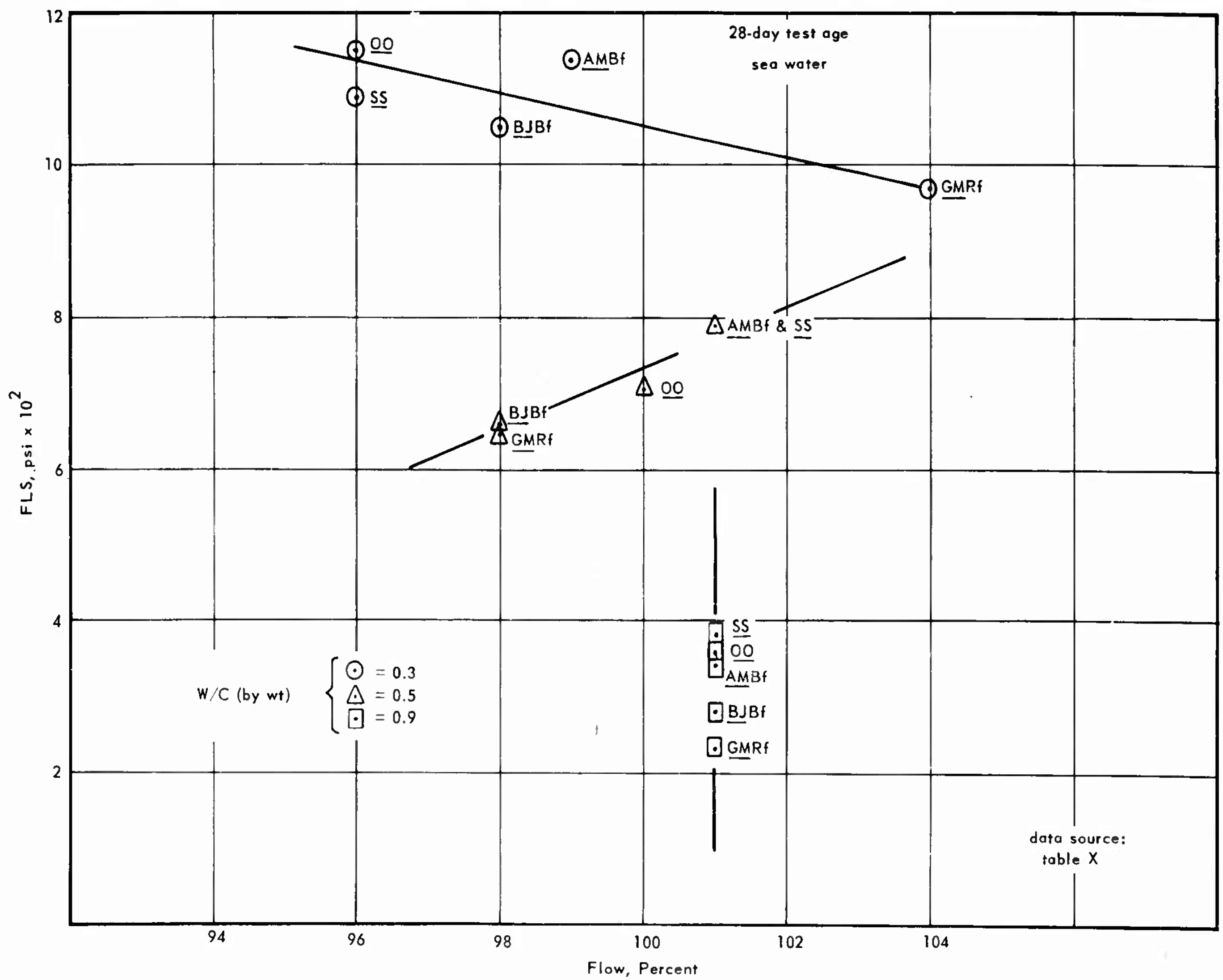

Figure 84. Correlation 8i-b'. (Part 2 of 4)

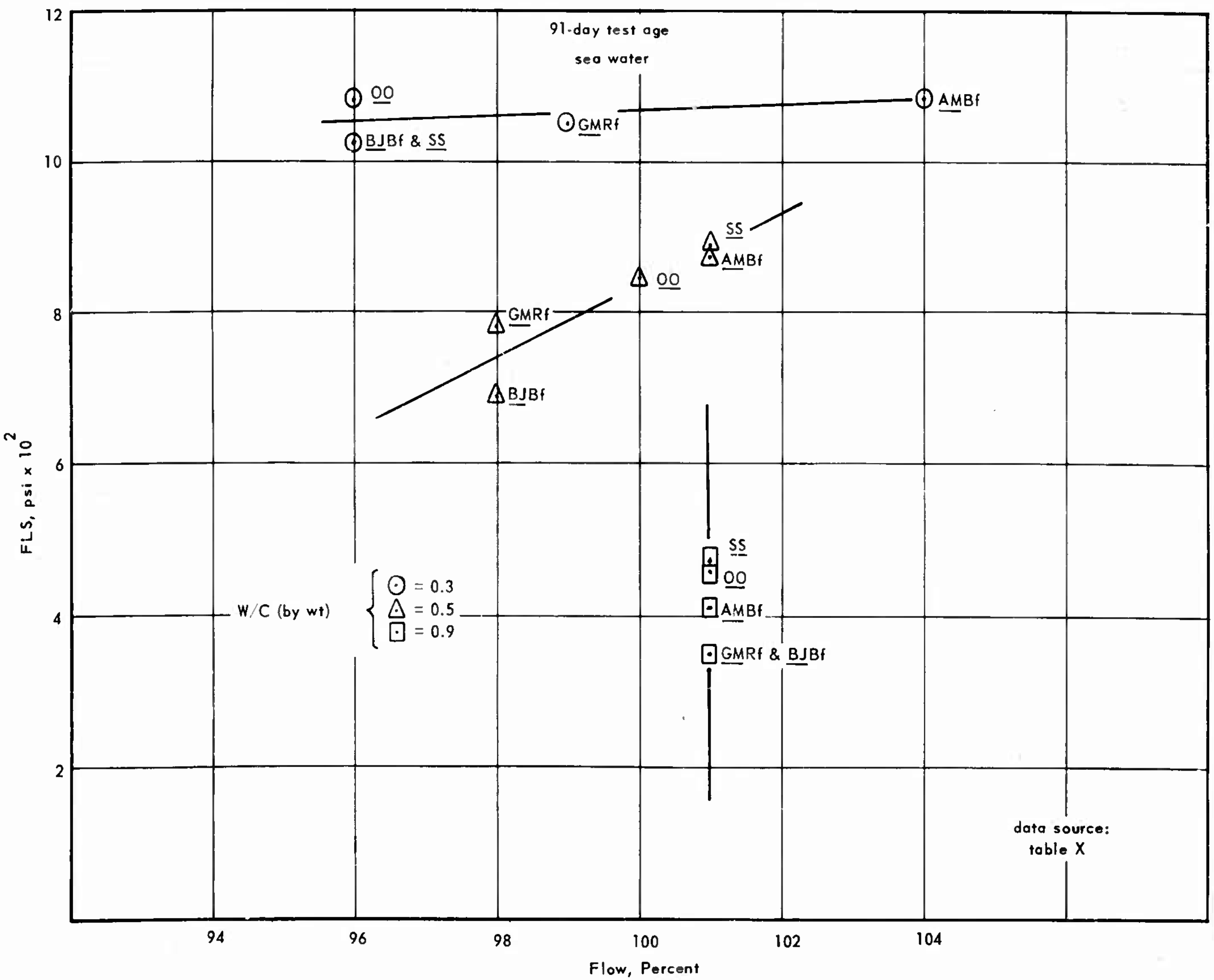

Figure 84. Correlation 8i-b'. (Part 3 of 4)

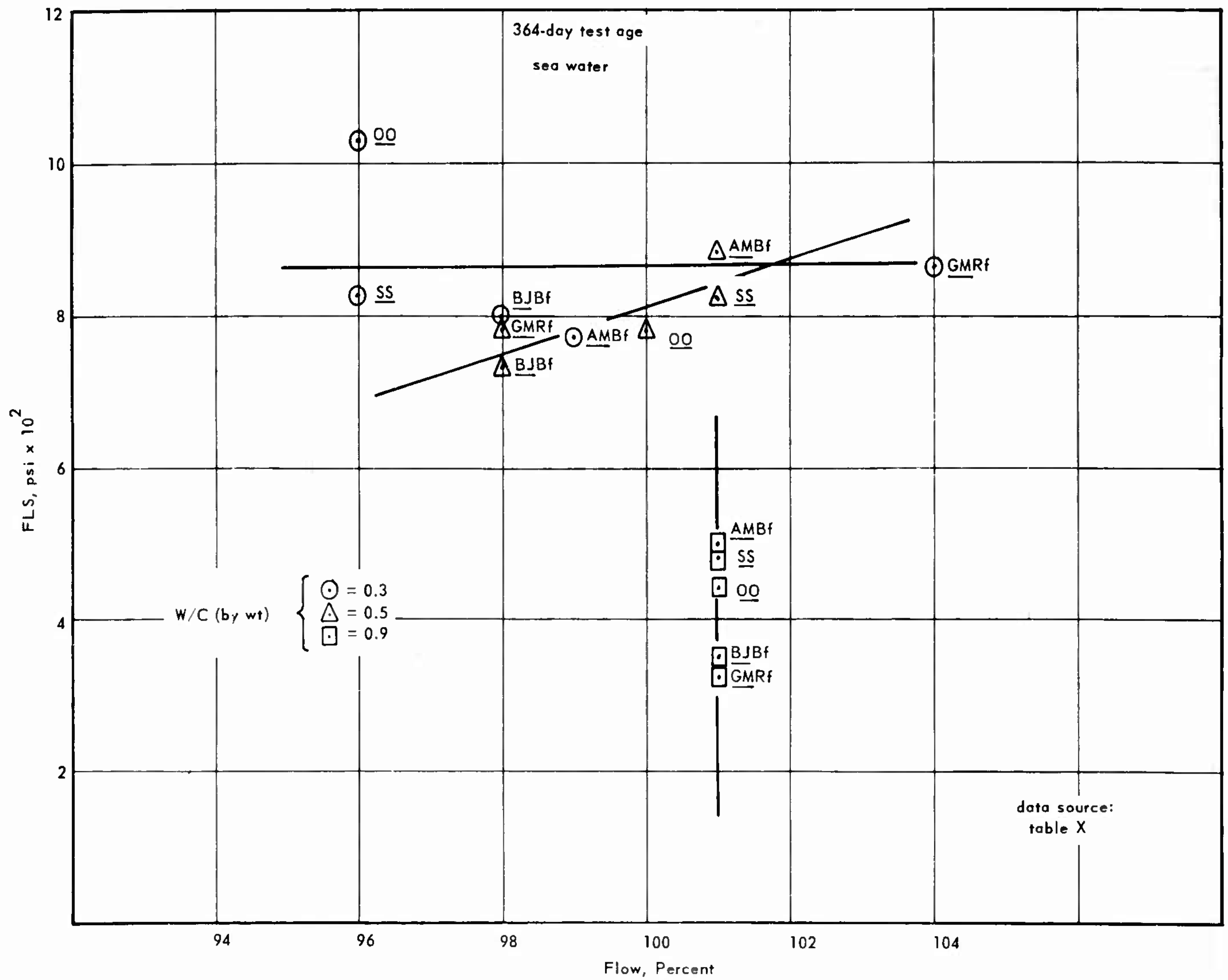

Figure 84. Correlation 8i-b'. (Part 4 of 4)

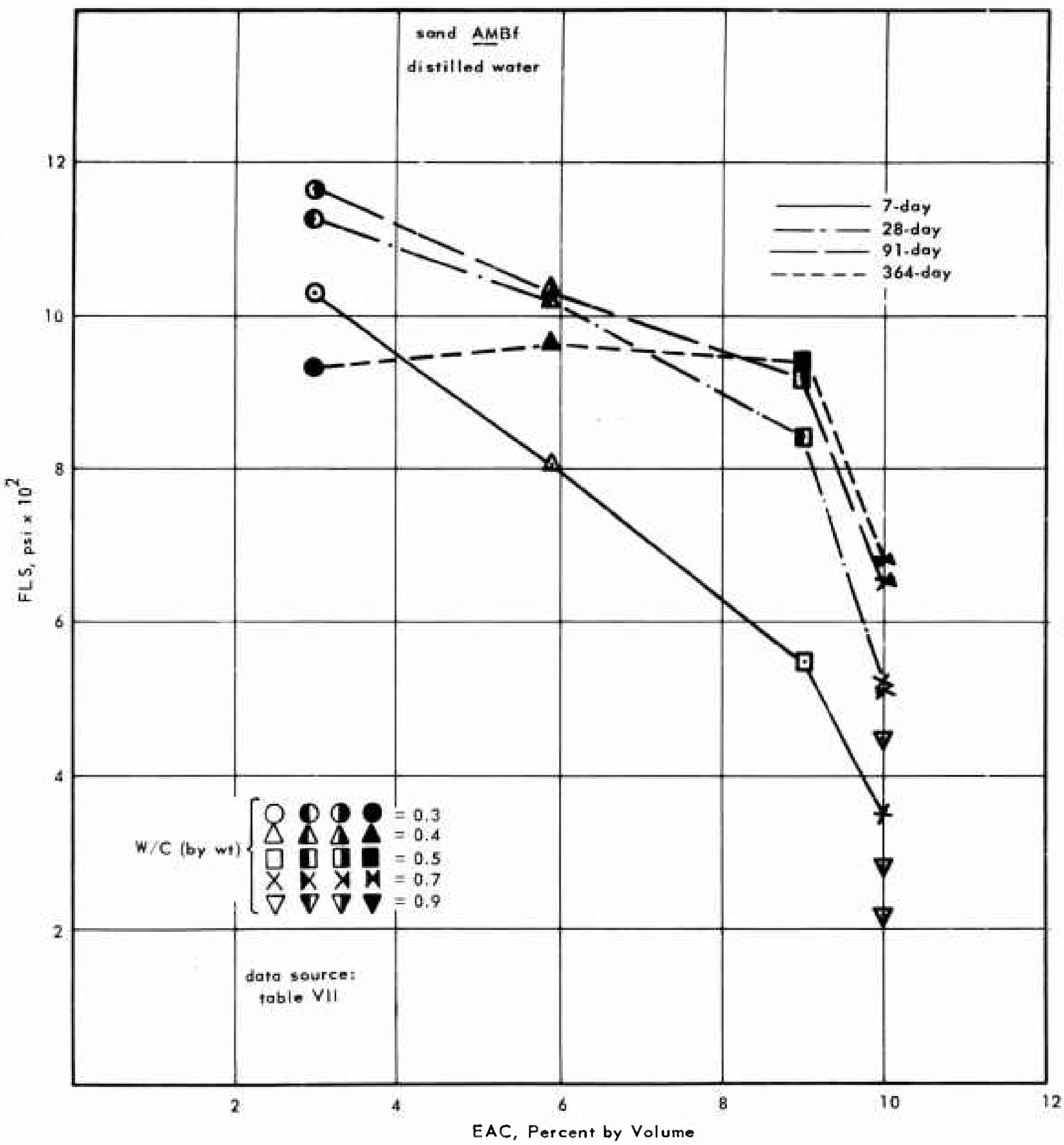

Figure 85. Correlation 8j-b'.

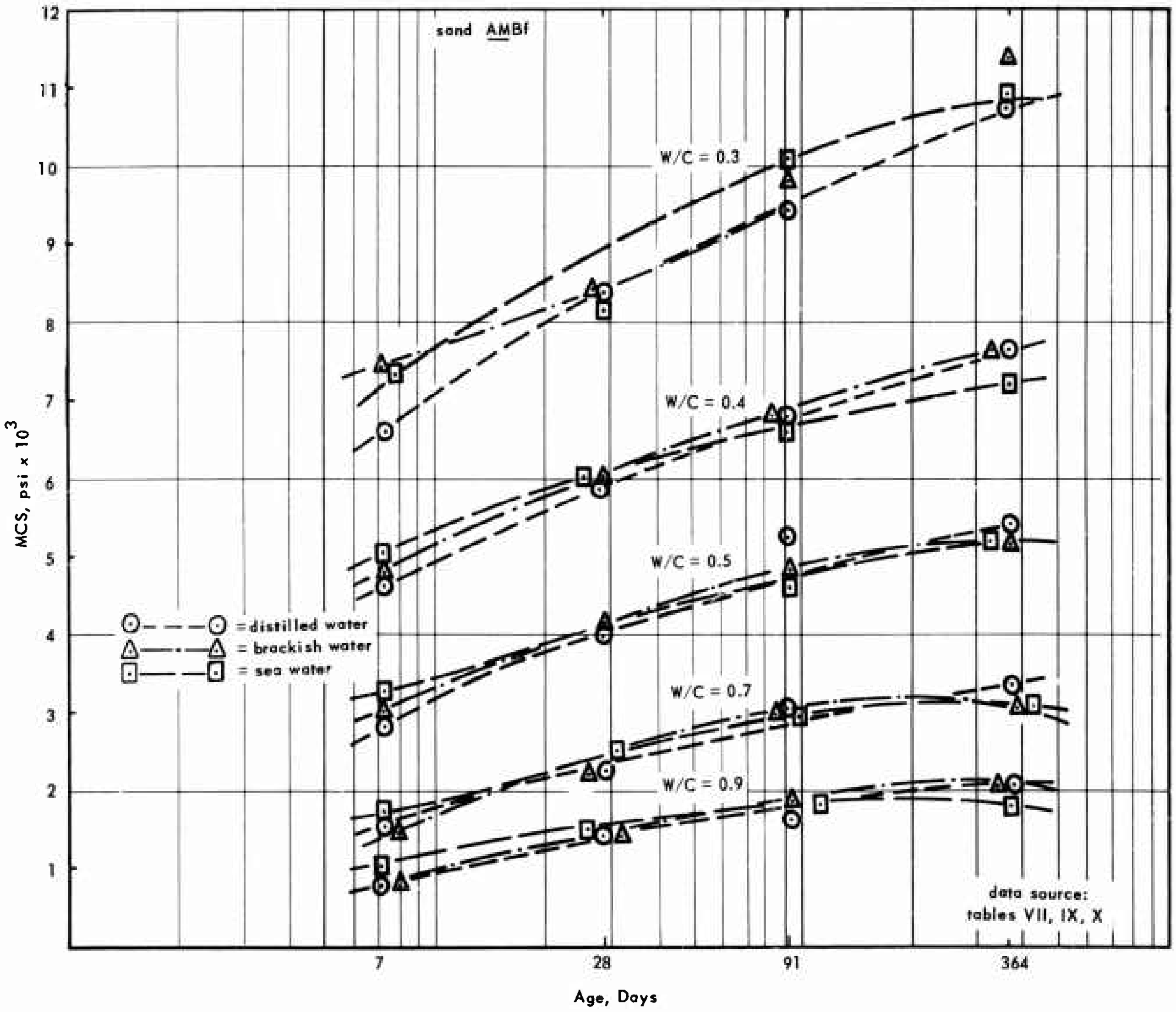

Figure 86. Correlations 8a-c' and 8b-c'. (Part 1 of 5)

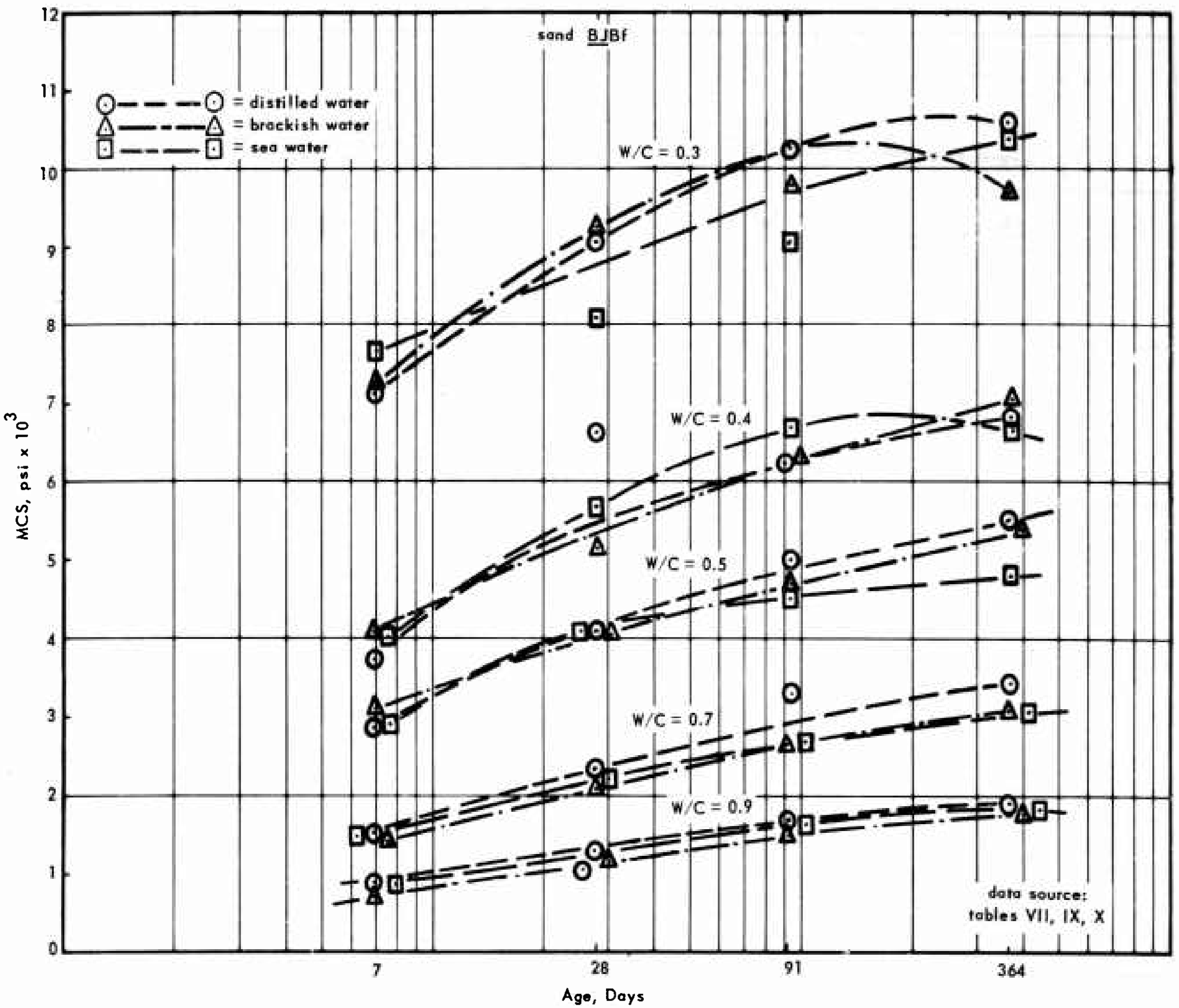

Figure 86. Correlations 8a-c' and 8b-c'. (Part 2 of 5)

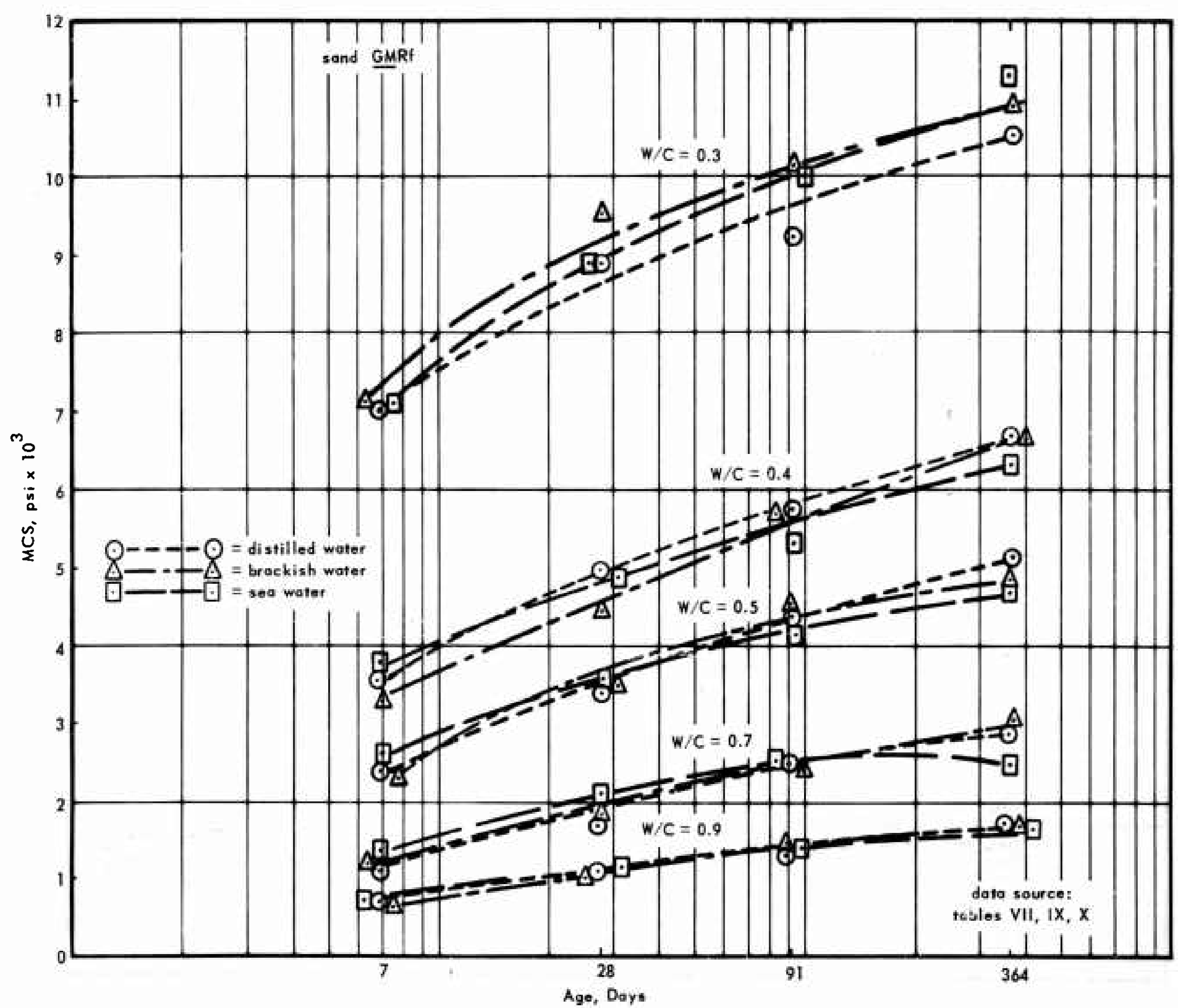

Figure 86. Correlations 8a-c' and 8b-c'. (Part 3 of 5)

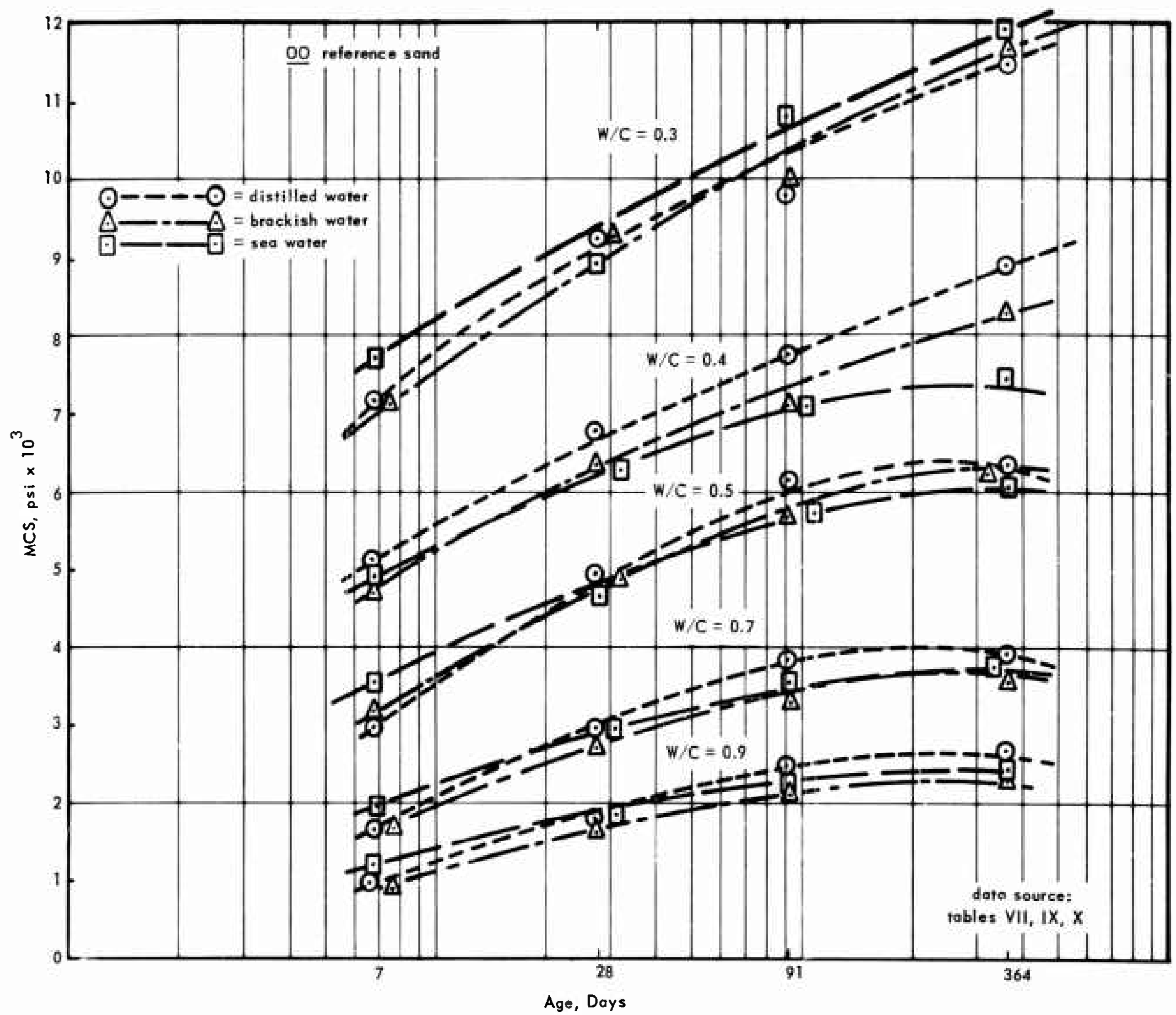

Figure 86. Correlations 8a-c' and 8b-c'. (Part 4 of 5)

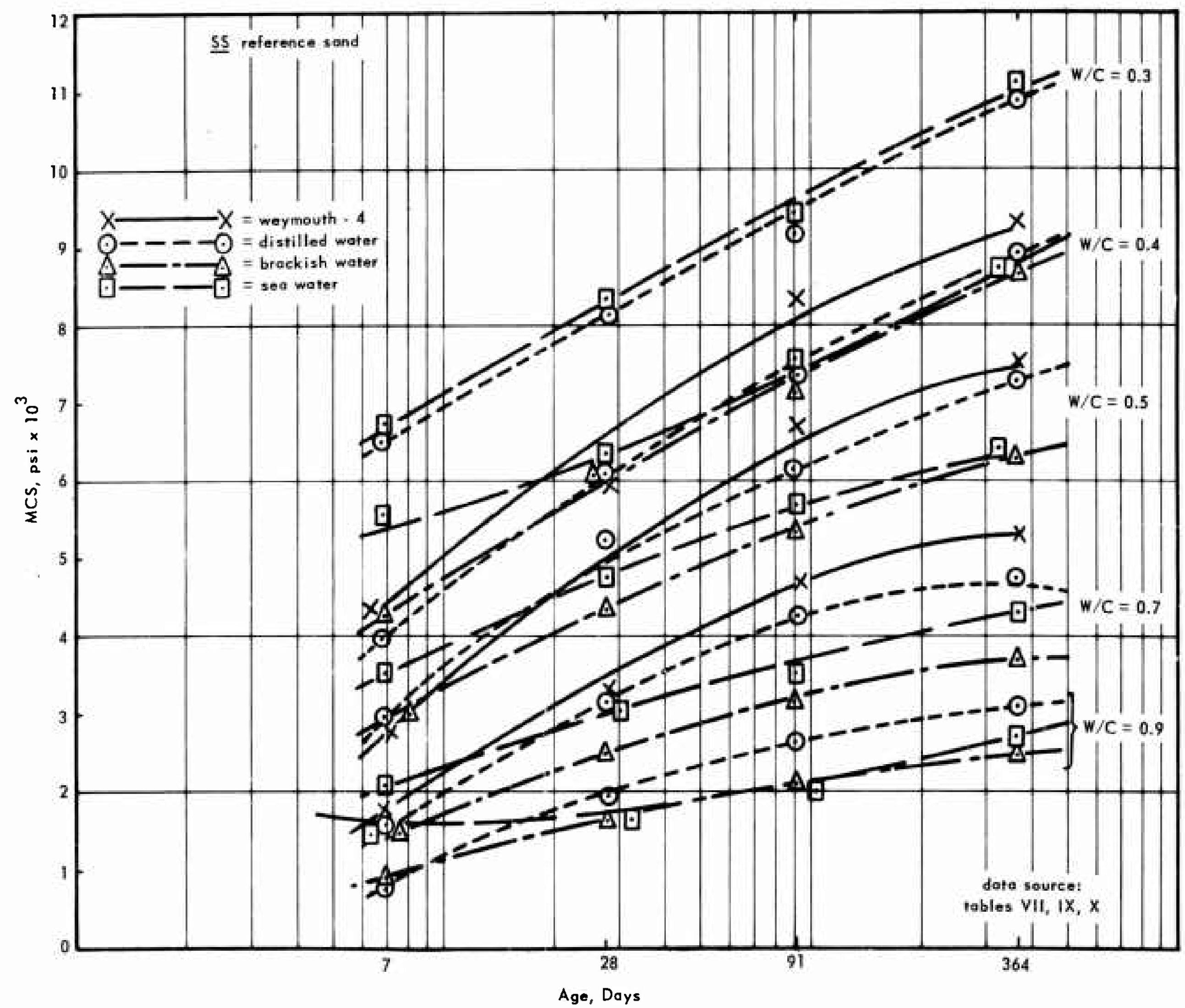

Figure 86. Correlations 8a-c' and 8b-c'. (Part 5 of 5)

Correlation 8b-c'.

As is evident from Figure 86, coral sand derived as R, B, or P material seems to bear no relationship to the expected MCS of the mortar, provided the natural gradation of the material is not altered. For example, in the case of distilled water and W/C value of 0.5, Table VIII shows that the order of magnitude of MCS at any age of one year or less is similar for all natural-graded coralline materials regardless of their derivation.

Correlation 8c-c'.

The variation of mortar MCS with sand voids is somewhat like the relationships observed under Correlation 8c-b', except that the rates of variation for mortars containing Q- or P-derived coral sands are about 20 times the rates attained with mortars containing R- or B-derived sands. Figure 87 depicts this trend at age 28 days for a mortar mix corresponding to that shown in Figure 72.

Correlation 8d-c'.

Not evaluated for reasons stated in Section 2. Nevertheless, it is of interest to note (Tables VII and VIII) that the highest MCS values pertaining to ENPcf, GMRf, and SS mortars are those obtainable when the sands are ideal-graded.

Correlation 8e-c'.

Unlike Figure 73, which pertains to Correlation 8e-b', Figure 88 indicates the impossibility of predicting MCS of a coral mortar on the basis of known CCS of the coral sand incorporated in that mortar.

Correlation 8f-c'.

The comments made in connection with Correlation 8f-b' apply equally well to the MCS of mortar, despite the general aspects in Table I footnote and in Section 2.

Correlation 8g-c'.

The variation of MCS with W/C is approximately the same for all mortars investigated, regardless of water type, sand derivation, or test age (not beyond one year). Figure 89 is typical of this trend. In nearly all cases the MCS value corresponding to a W/C of 0.3 is between four and five times the MCS obtainable when the W/C is 0.9. Figure 90 illustrates the similar trends obtained with OO reference mortars in the preliminary series.

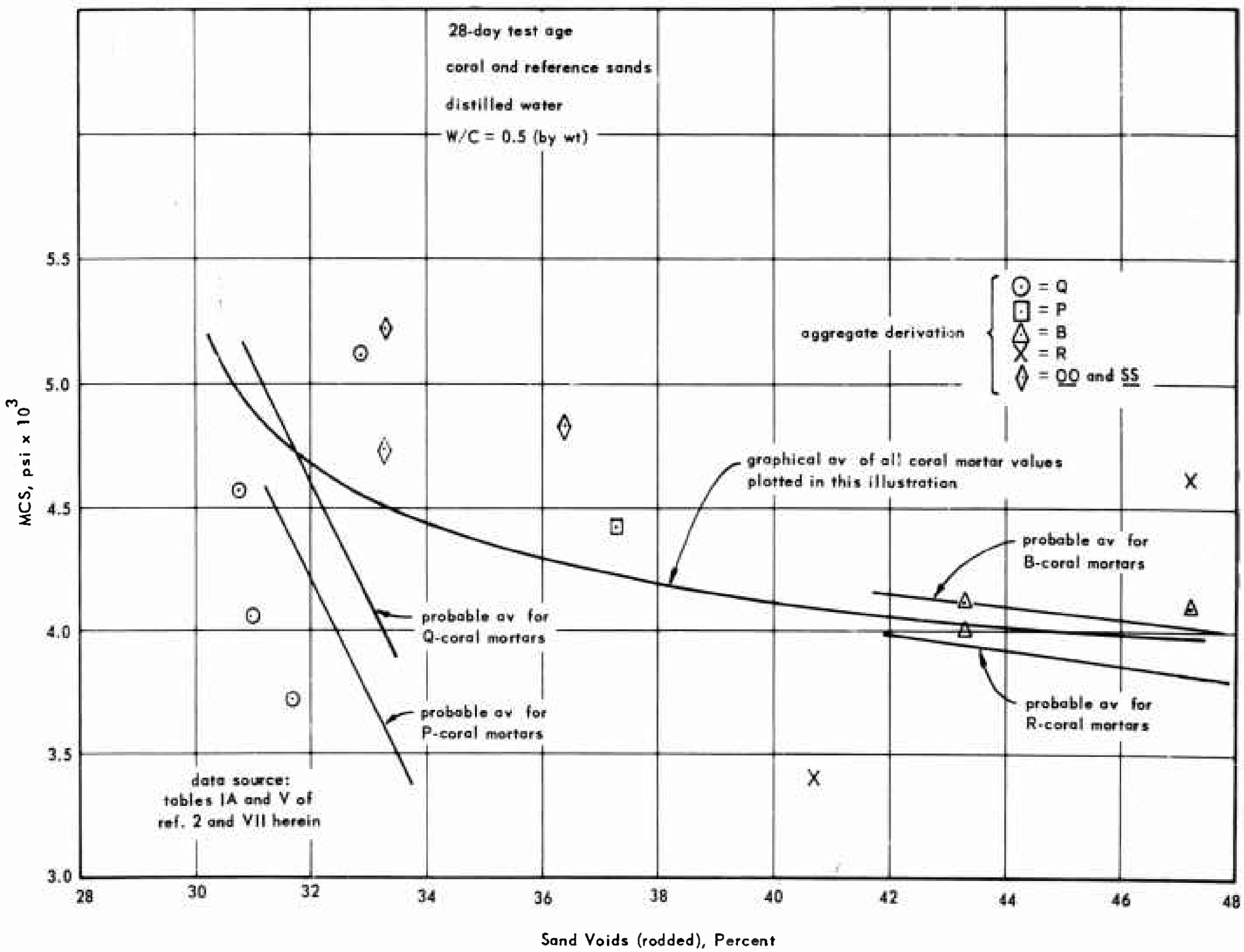

Figure 87. Correlation 8c-c'.

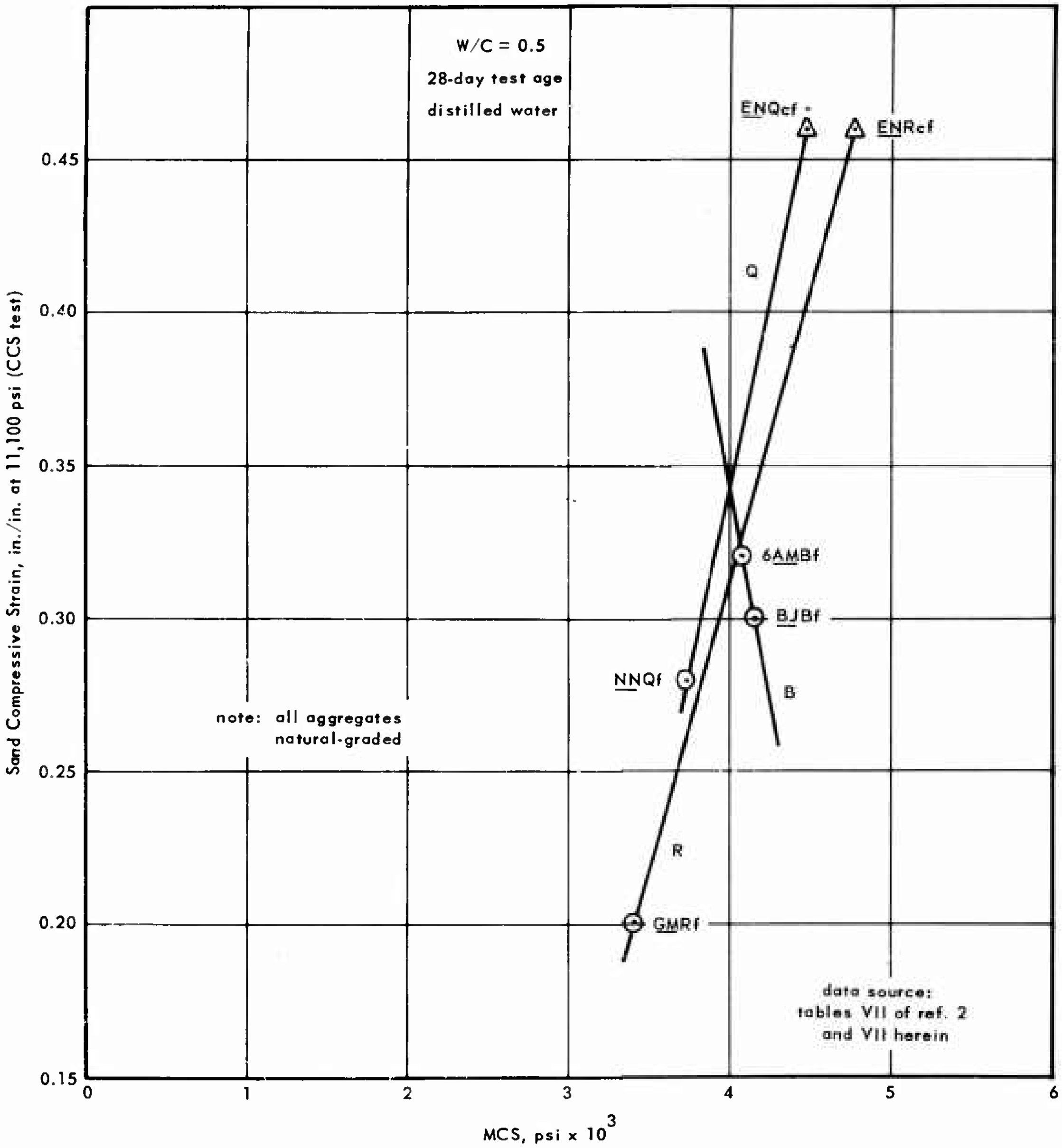

Figure 88. Correlation 8e-c'.

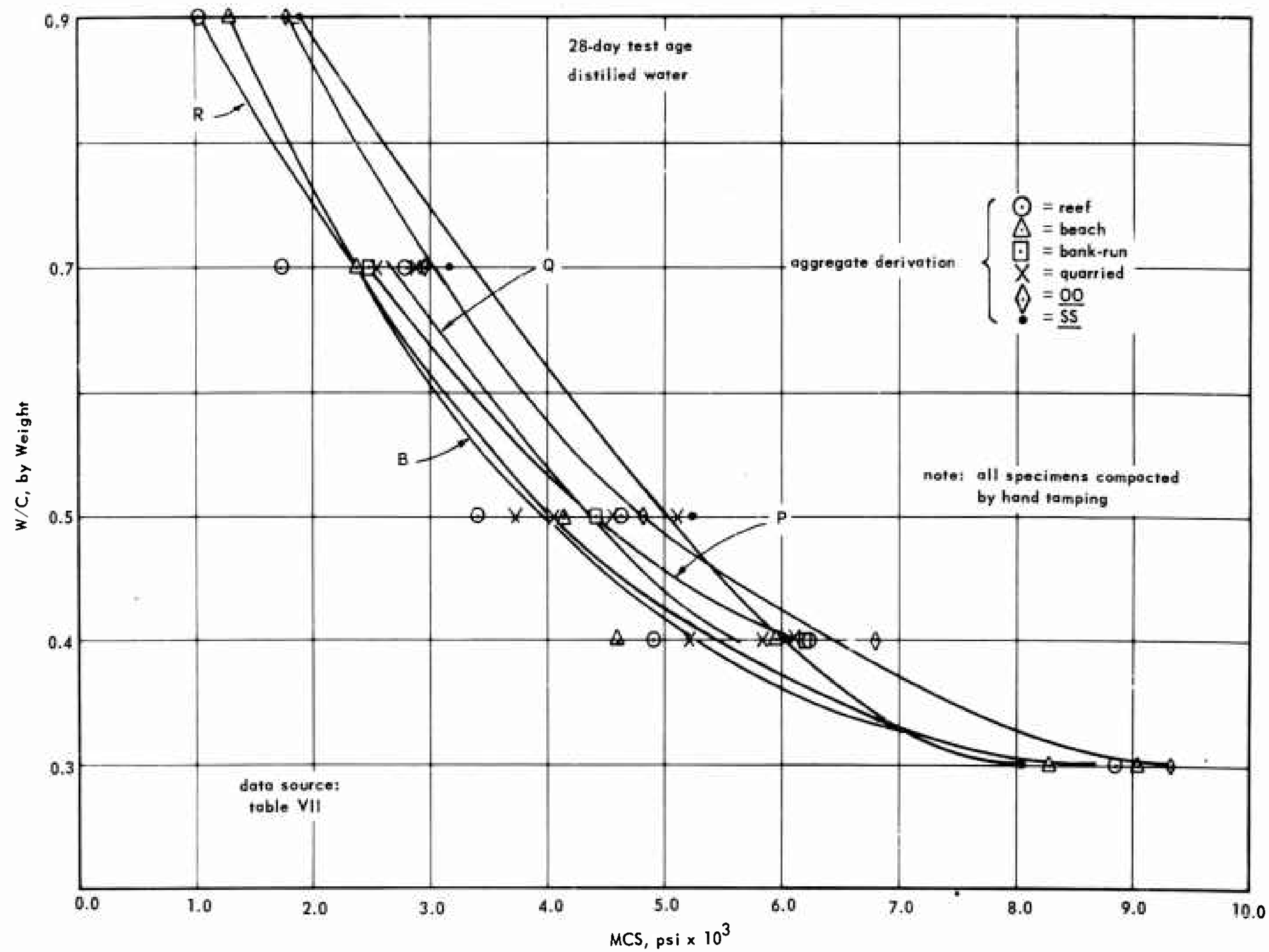

Figure 89. Correlation 8g-c'.

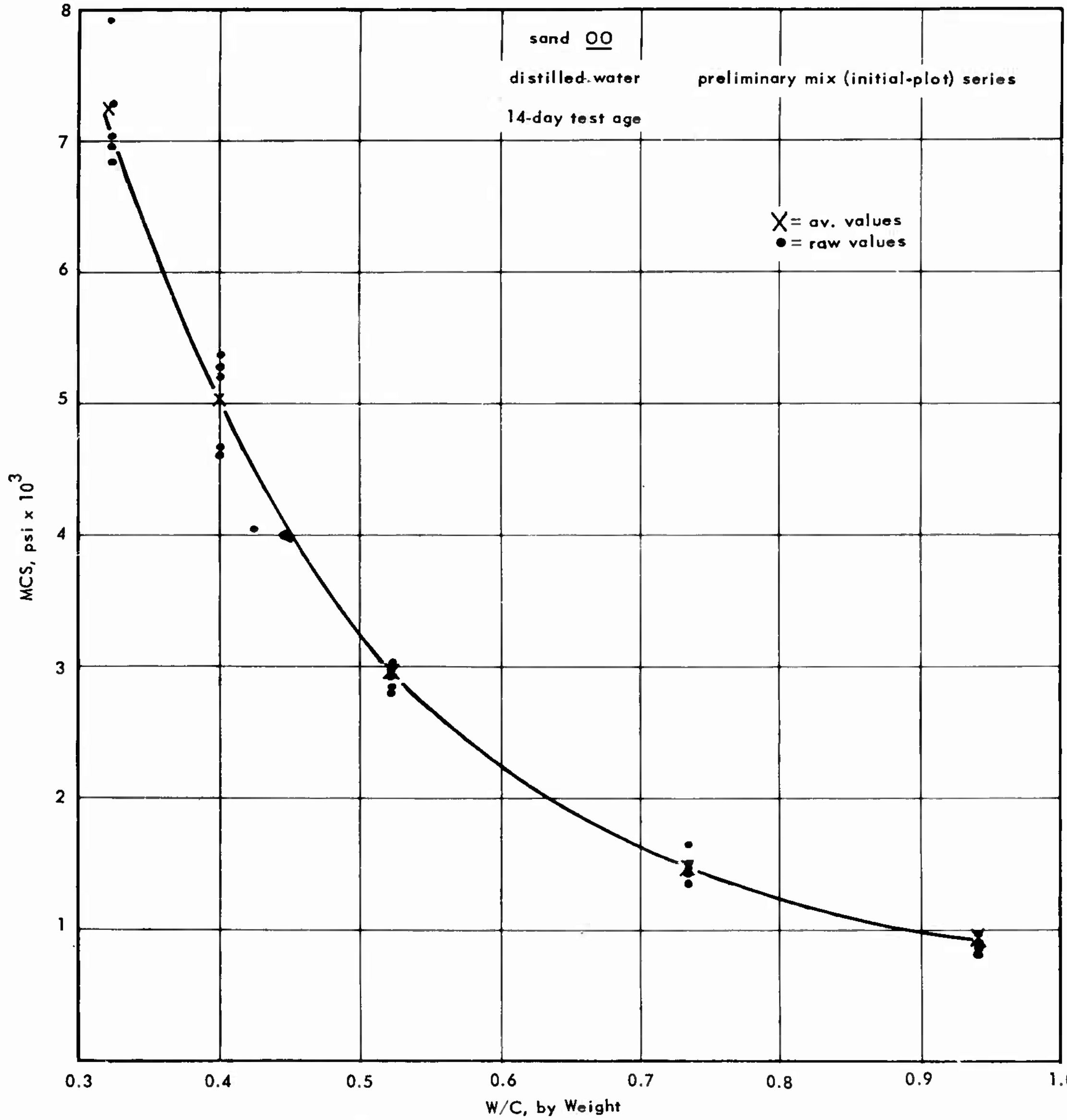

Figure 90. Correlation 8g-c'. (Part 1 of 3)

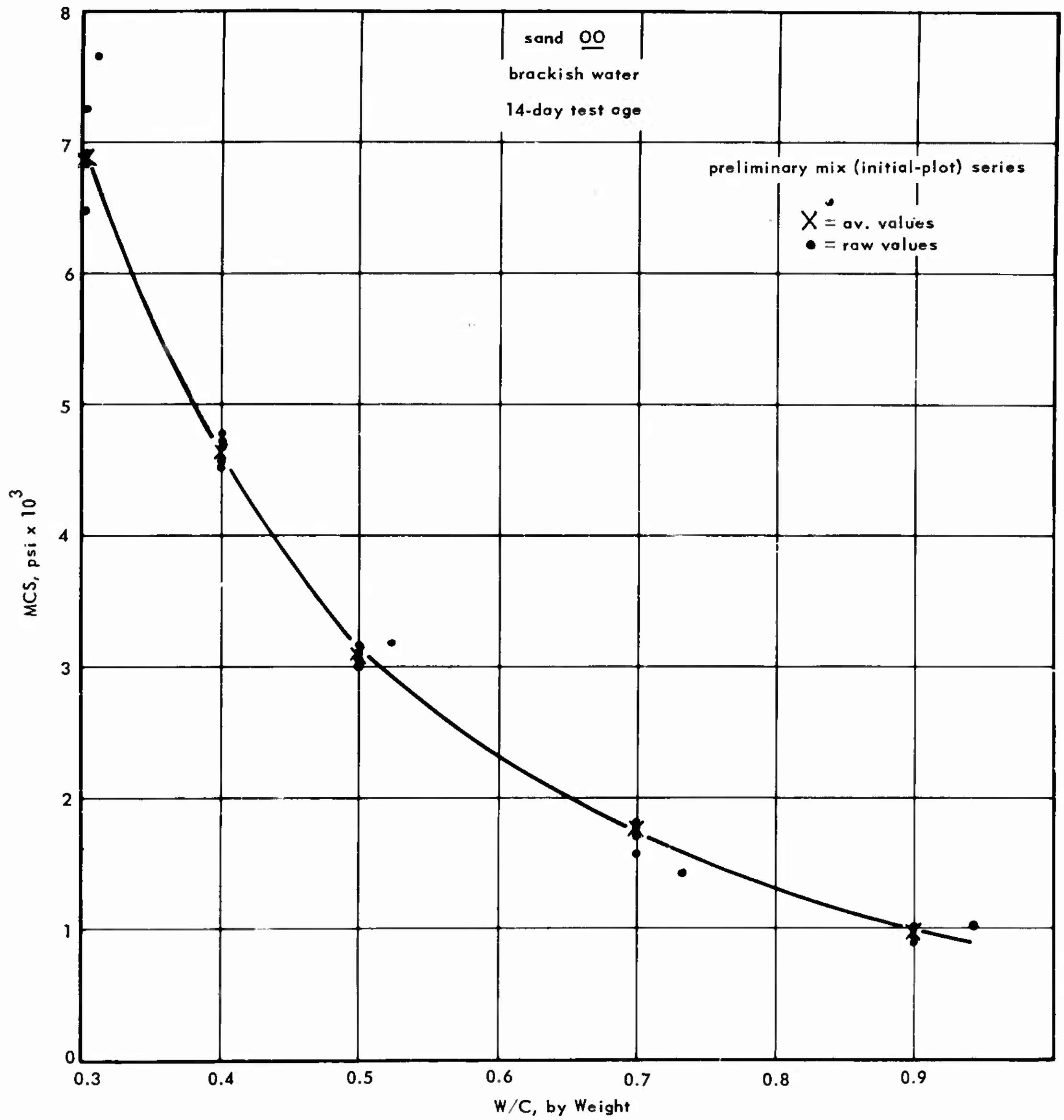

Figure 90. Correlation 8g-c'. (Part 2 of 3)

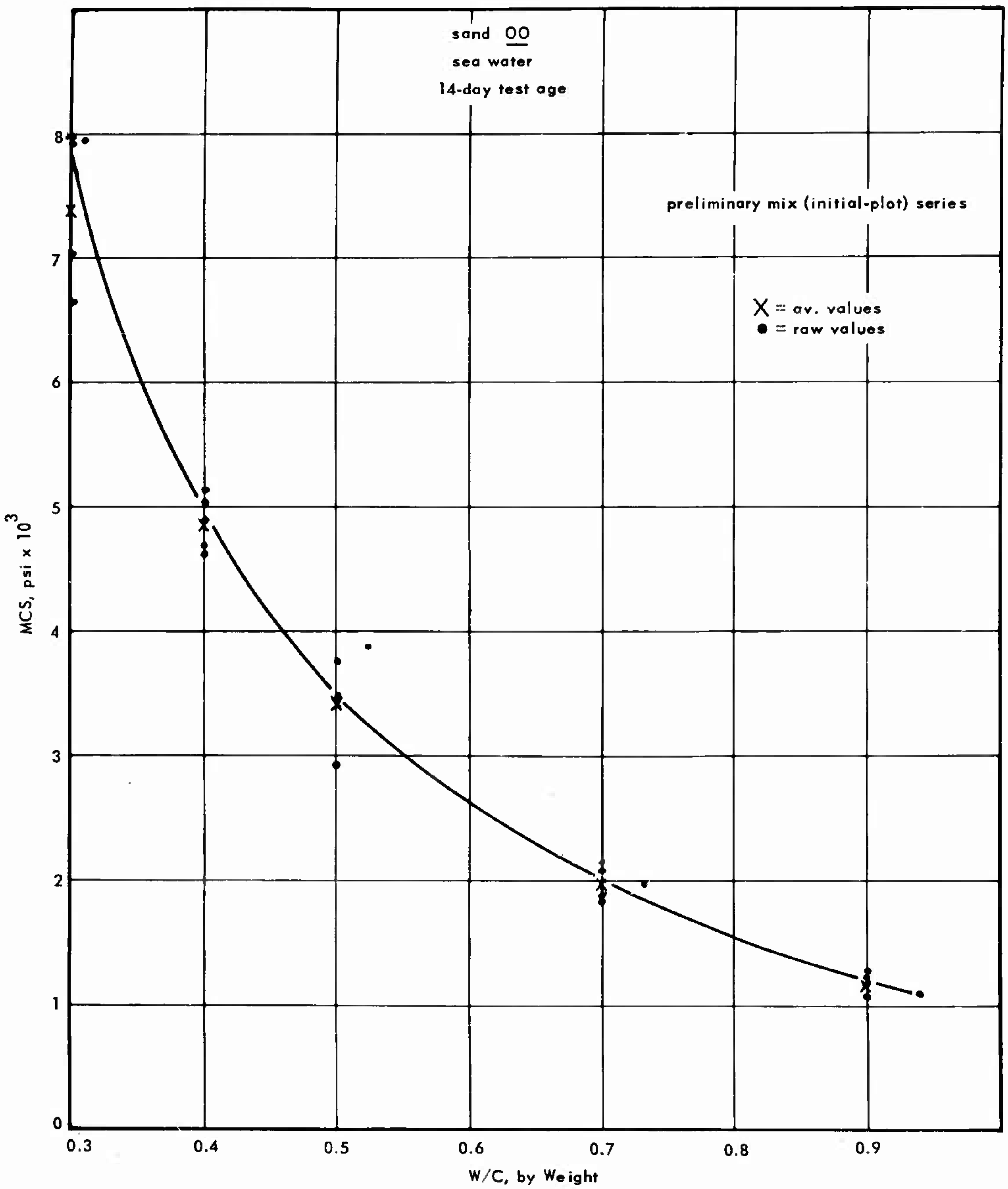

Figure 90. Correlation 8g-c'. (Part 3 of 3)

Correlation 8h-c'.

Changes in the A/C produce variations in the MCS of mortars as exemplified by Figure 91. The relative positions of the Q, P, B, and R coral sand mortar curves are, of course, approximate; but the general configuration is believed typical when considered in the light of Figures 92, 93, and 94. The last three figures reveal no unusual dissimilarities between the various mortars (incorporating a specific type of water) at any age between one week and one year.

Correlation 8i-c'.

No particular pattern can be established, from the available data, concerning mortar flow and MCS.

Correlation 8j-c'.

Based on the data shown in Tables VII to X, inclusive, the variation of MCS with percent EAC probably can be expressed mathematically as a parabolic or hyperbolic function. The descending order of MCS values, with increasing EAC, is nearly a reflection of the situation pertaining to Correlation 8j-b'.

Correlation 9a-a'.

Examination of data in Tables VII and XI, Tables IX and XII, and Tables X and XIII indicates that as a general rule an increase in mortar BUD reflects a corresponding increase in mortar DYE. This holds true when comparing BUD and DYE values at equal ages.

Correlation 9b-a'.

Increase in mortar FLS reflects an increase in mortar DYE. This is exemplified by Figure 95 which is typical for the regular series of mixes investigated, and by Figure 96 which pertains to similar trends observed in the preliminary series of mixes.

Correlation 9a-b'.

This relationship is illustrated in Figures 97 and 98, which are self-explanatory. A noteworthy feature of Figure 98 is the fact that the curve for sea-water mortar begins to regress at a FLS that is 200 psi higher than for the case of brackish-water mortar; no regression is evident when distilled water is used. At equal ages, an increase in BUD reflects an increase in FLS. This is true, in general, for all mortars investigated in the Group B Schedule of experiments.

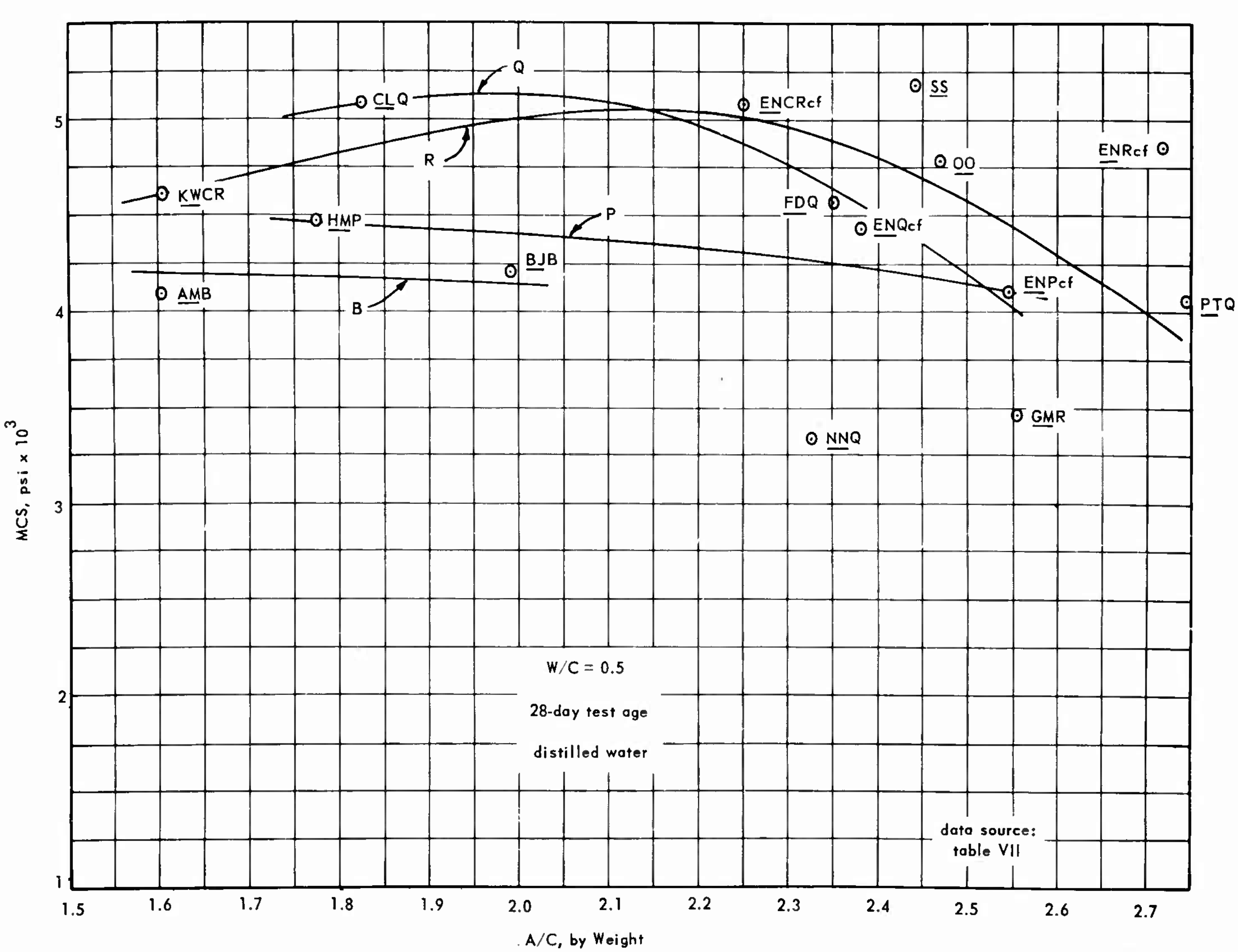

Figure 91. Correlation 8h-c'.

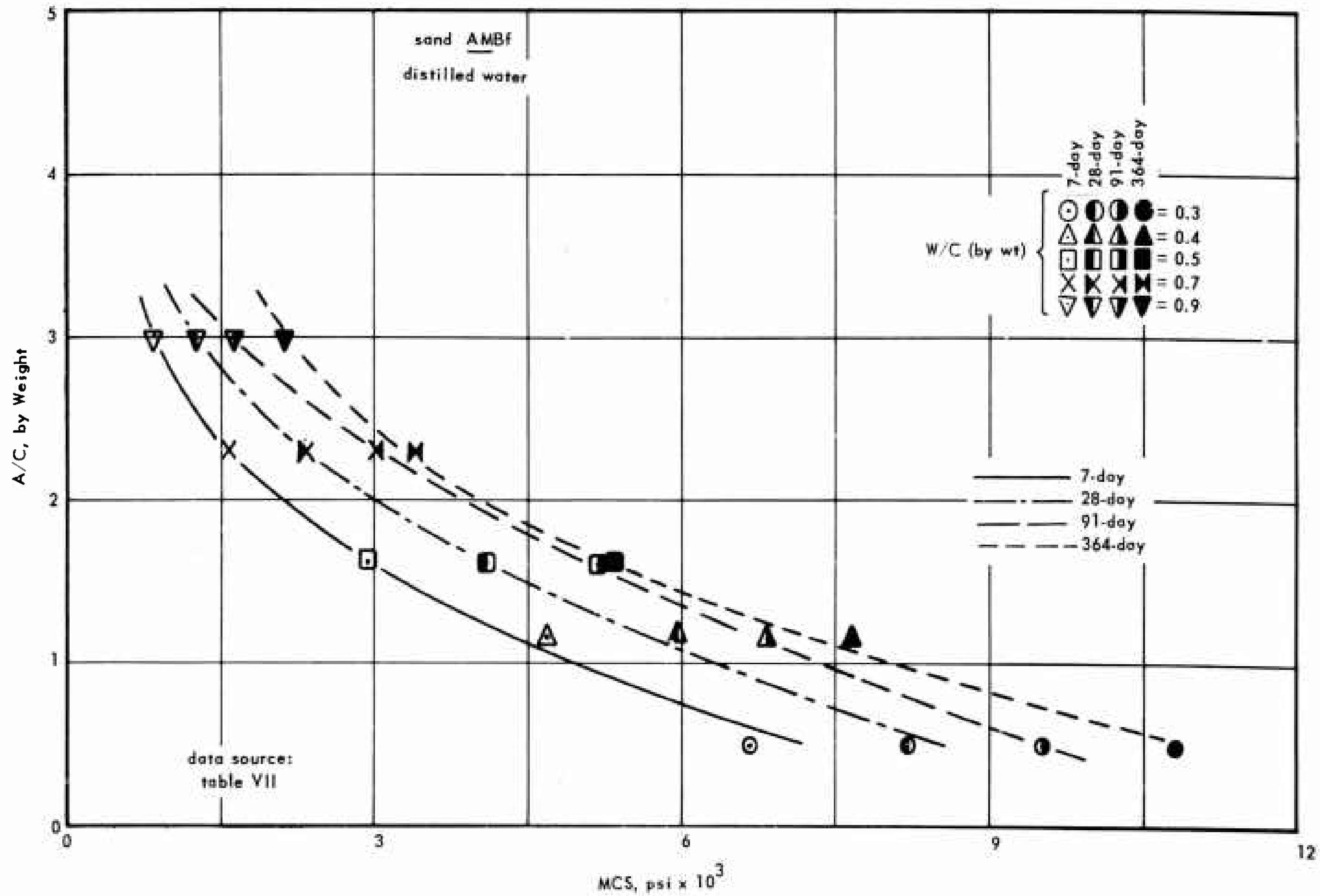

Figure 92. Correlation 8h-c'. (Part I of 5)

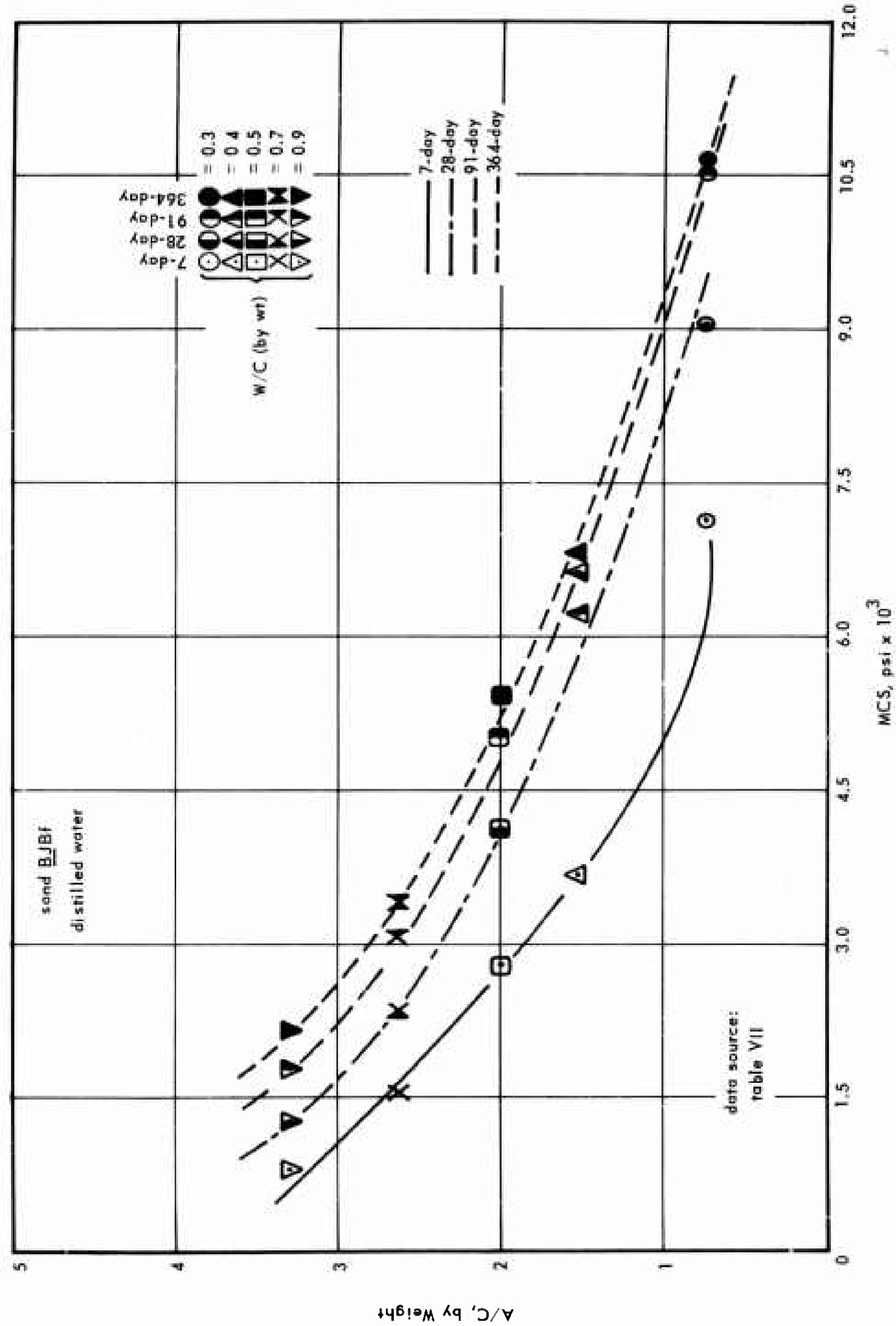

Figure 92. Correlation 8h-c'. (Part 2 of 5)

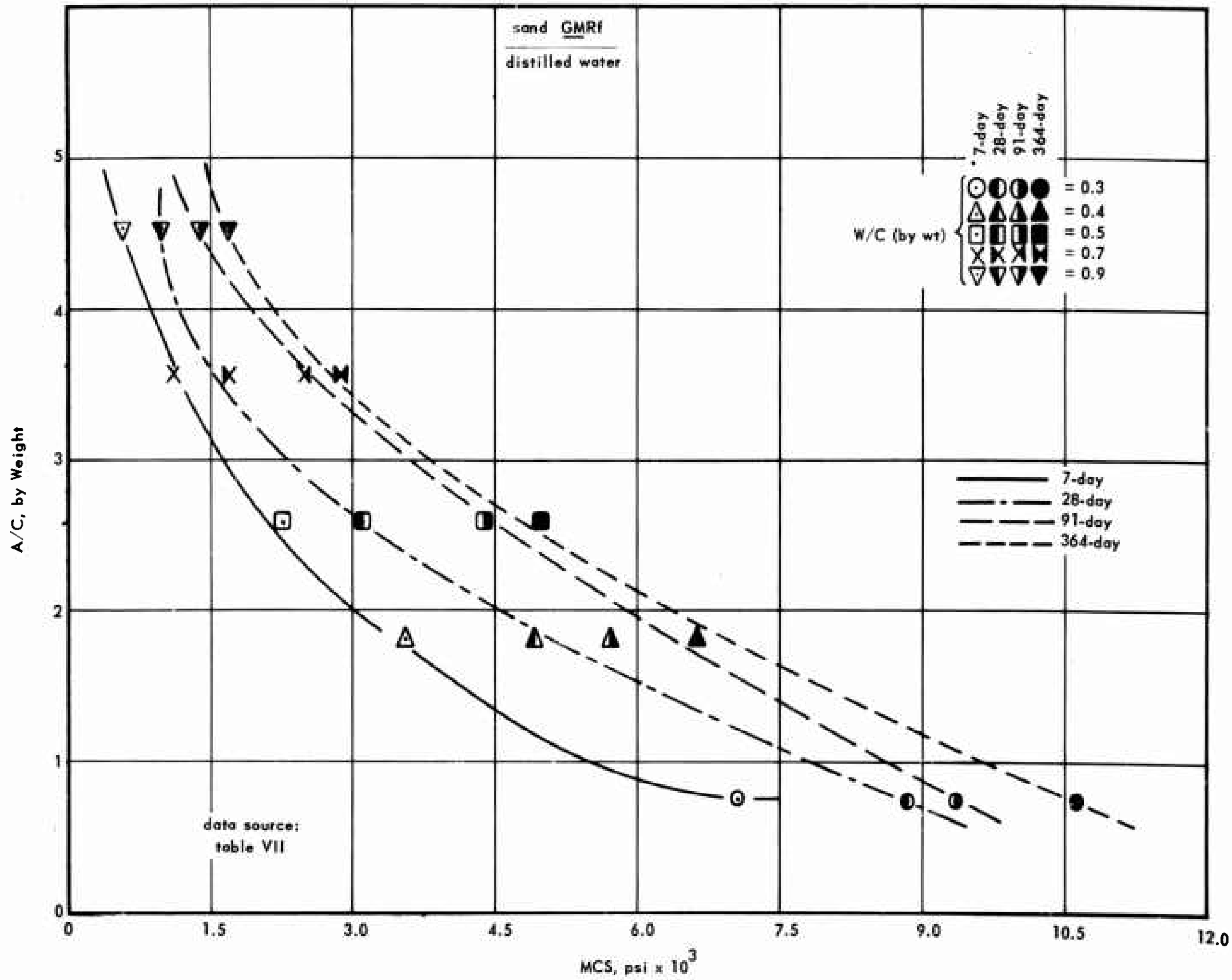

Figure 92. Correlation 8h-c'. (Part 3 of 5)

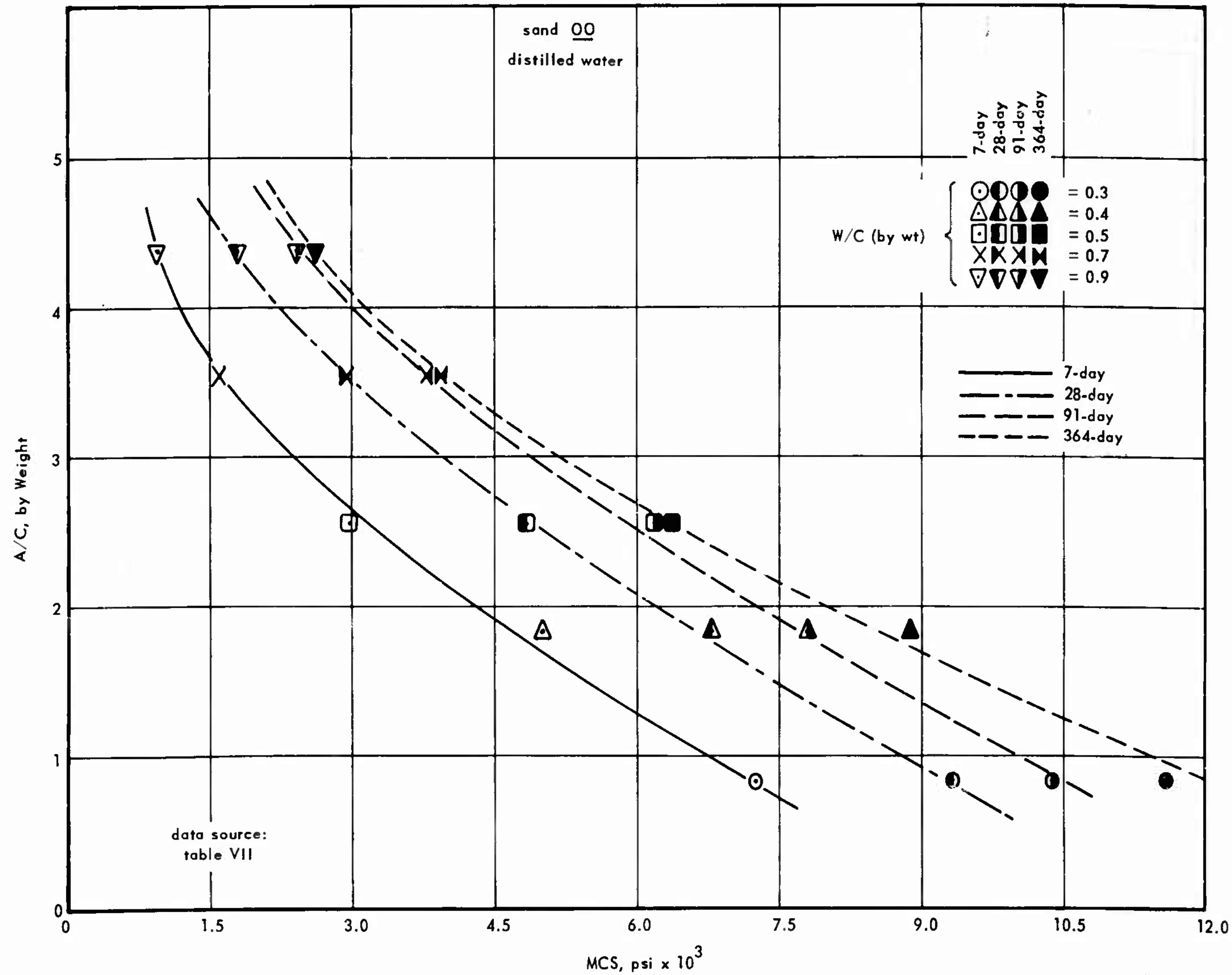

Figure 92. Correlation 8h-c'. (Part 4 of 5)

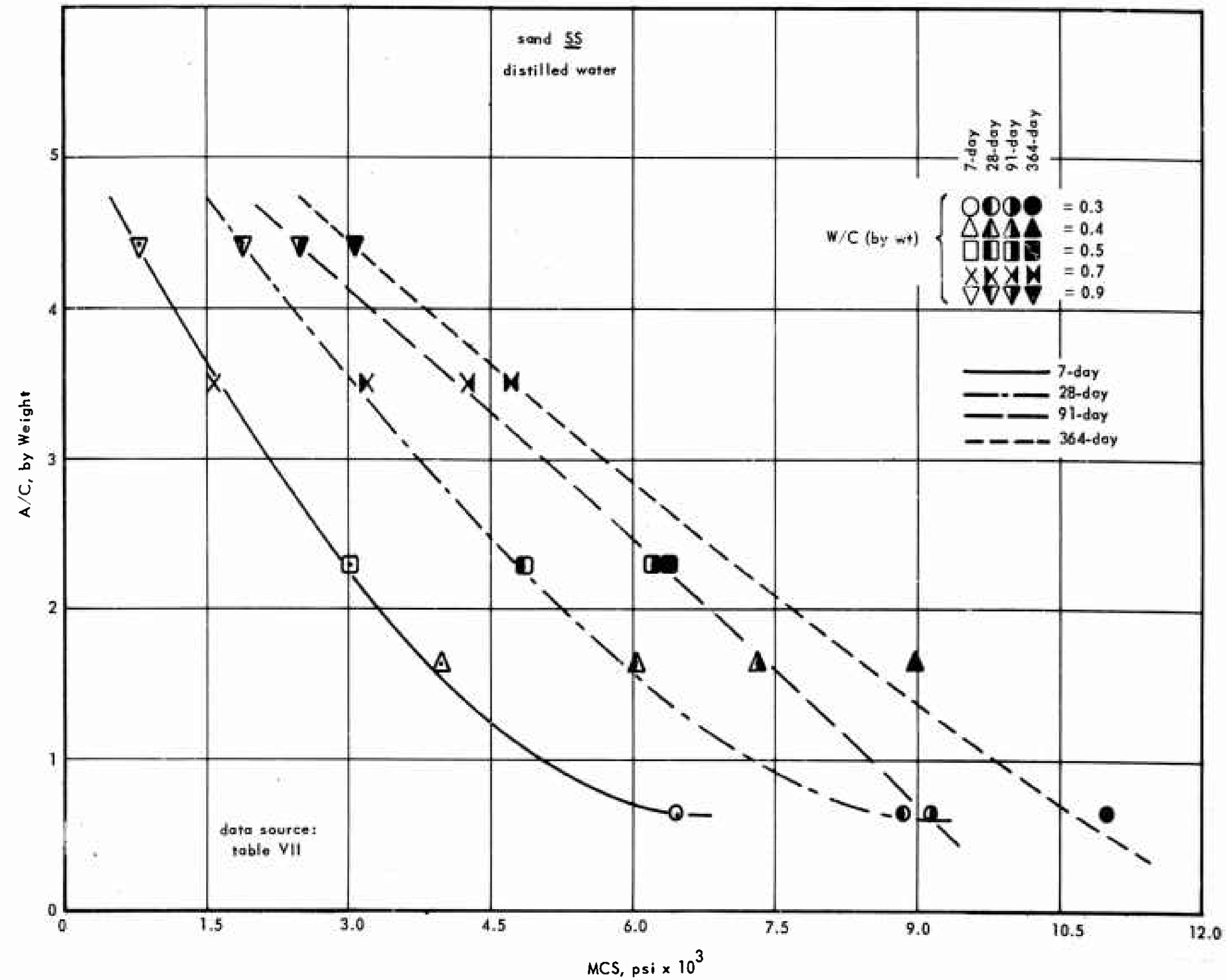

Figure 92. Correlation 8h-c'. (Part 5 of 5)

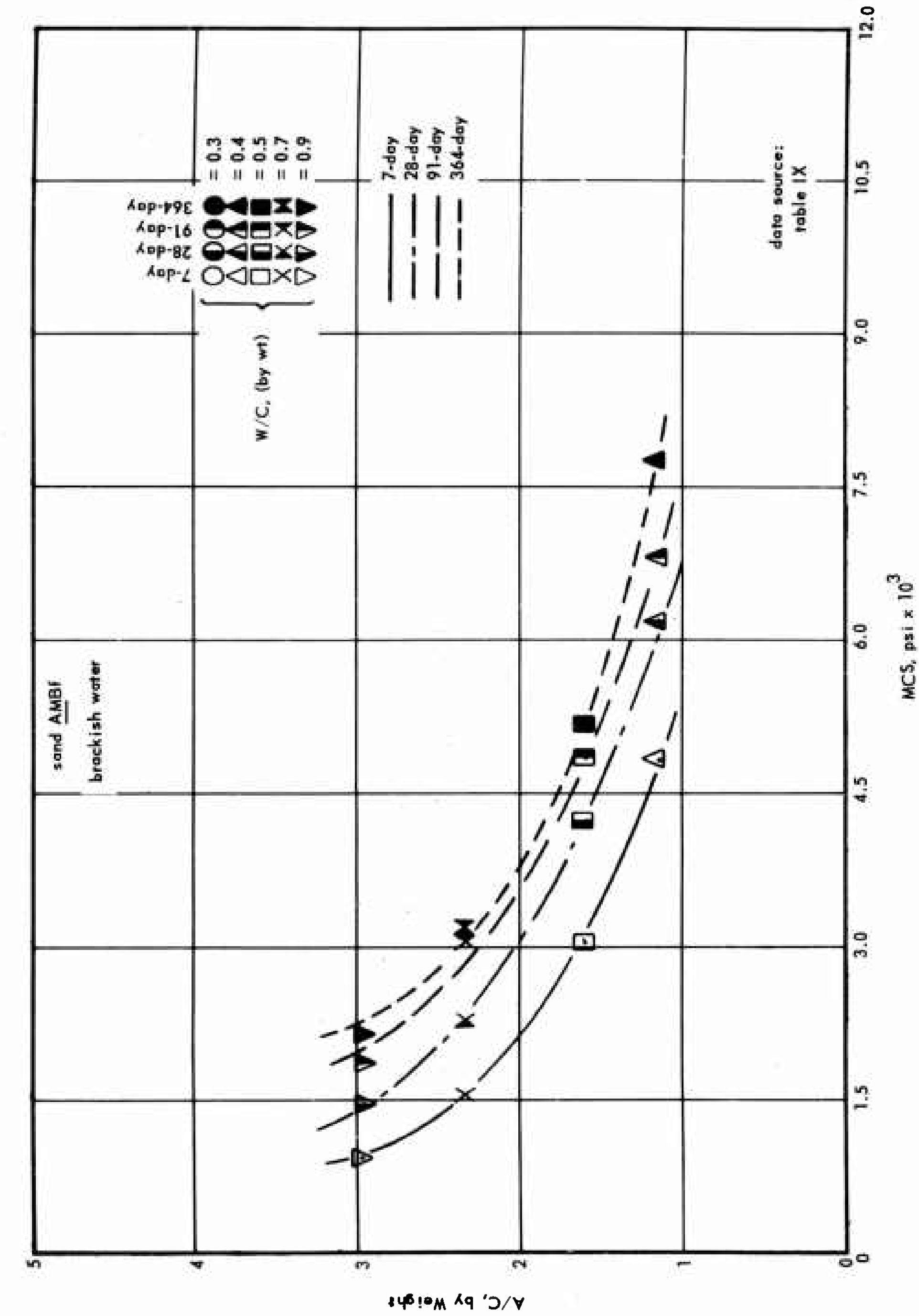

Figure 93. Correlation 8h-c'. (Part 1 of 5)

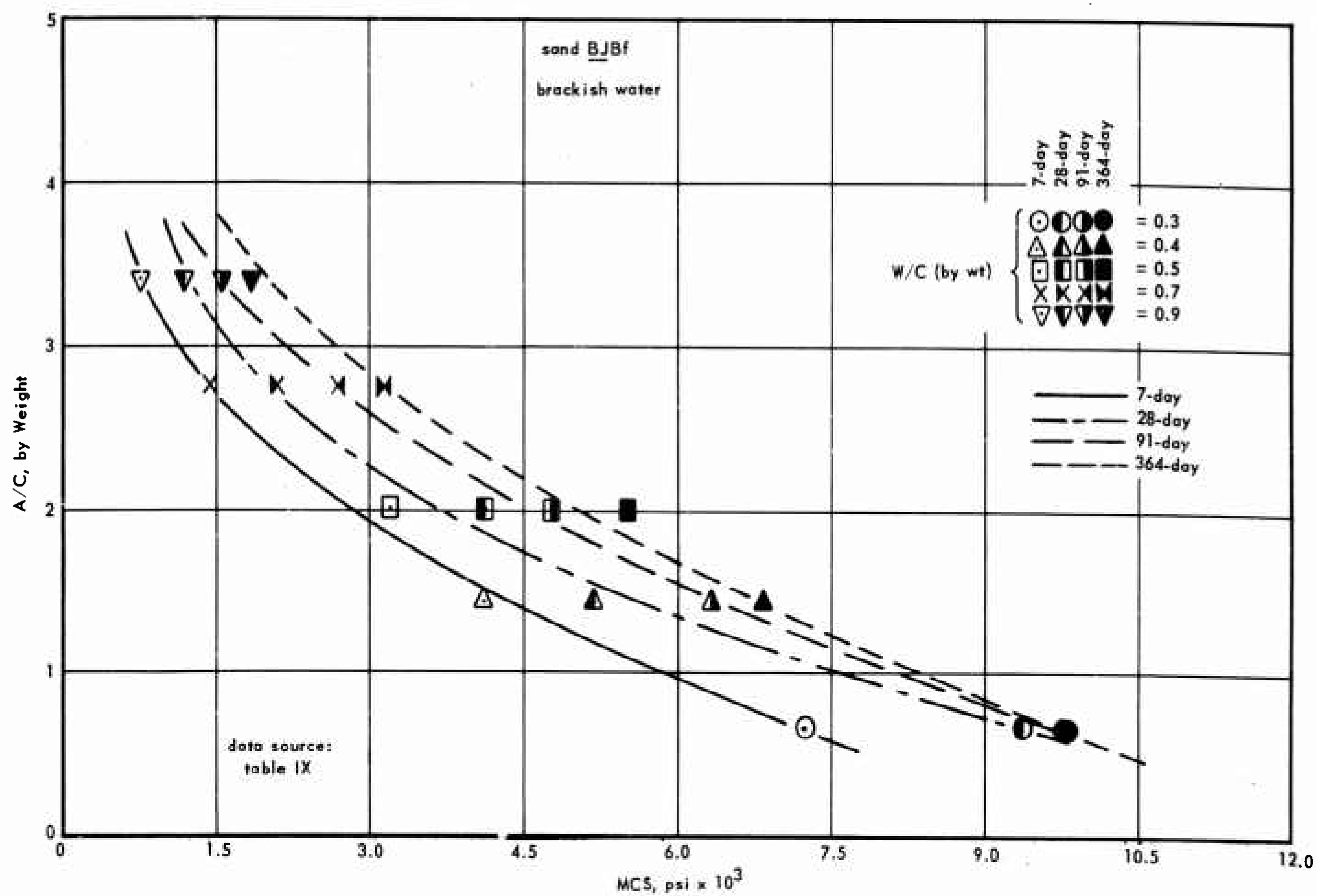

Figure 93. Correlation 8h-c'. (Part 2 of 5)

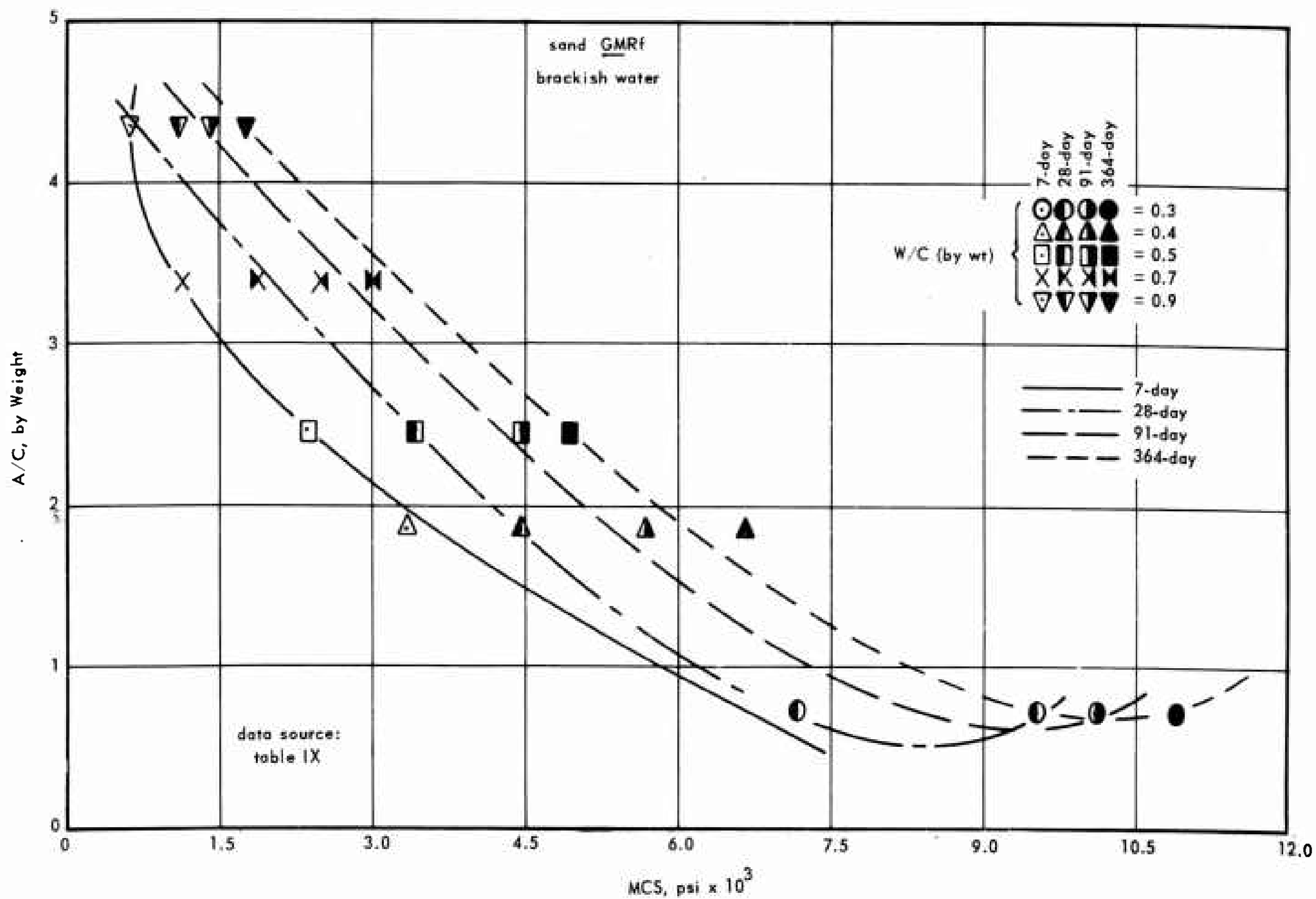

Figure 93. Correlation 8h-c'. (Part 3 of 5)

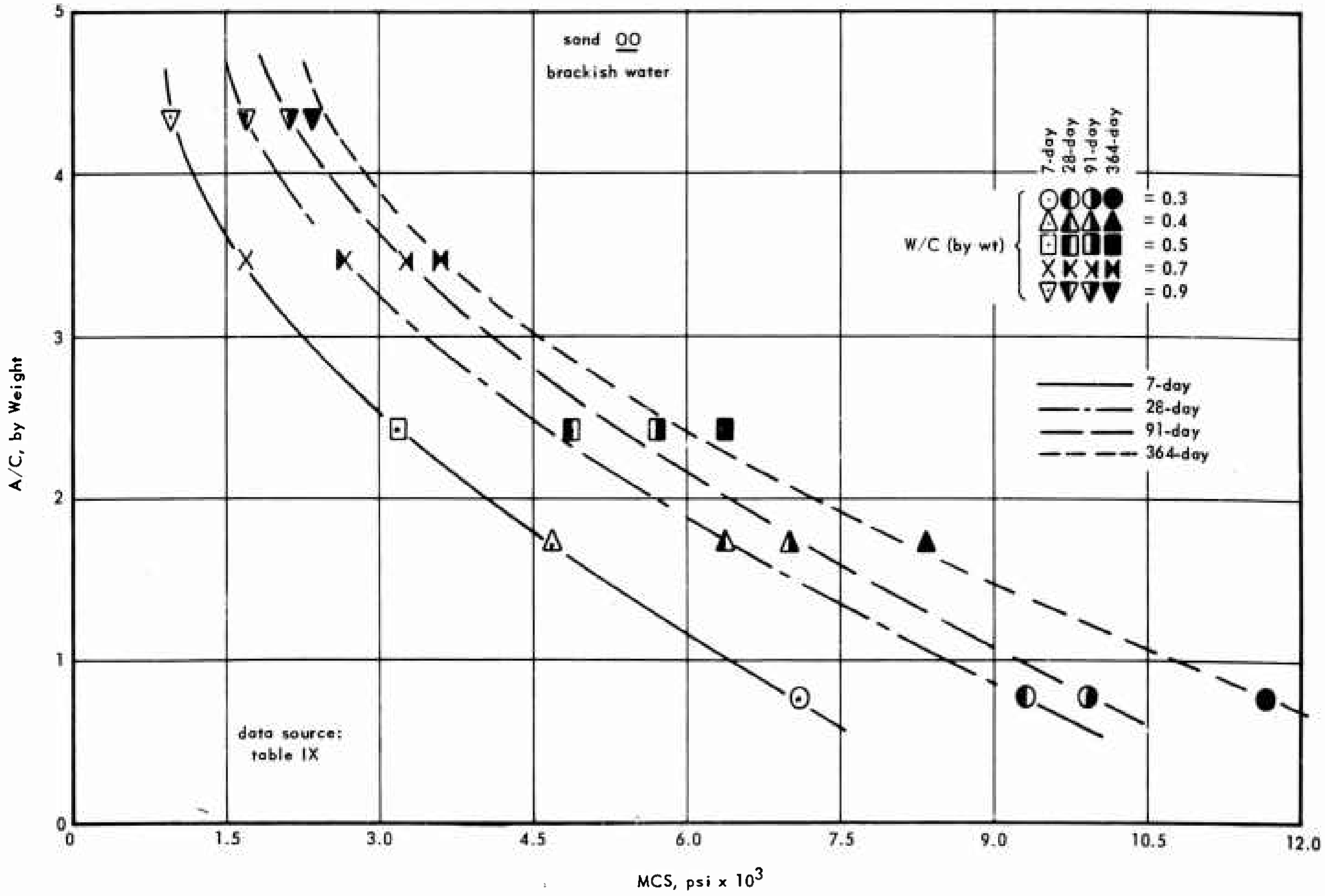

Figure 93. Correlation 8h-c'. (Part 4 of 5)

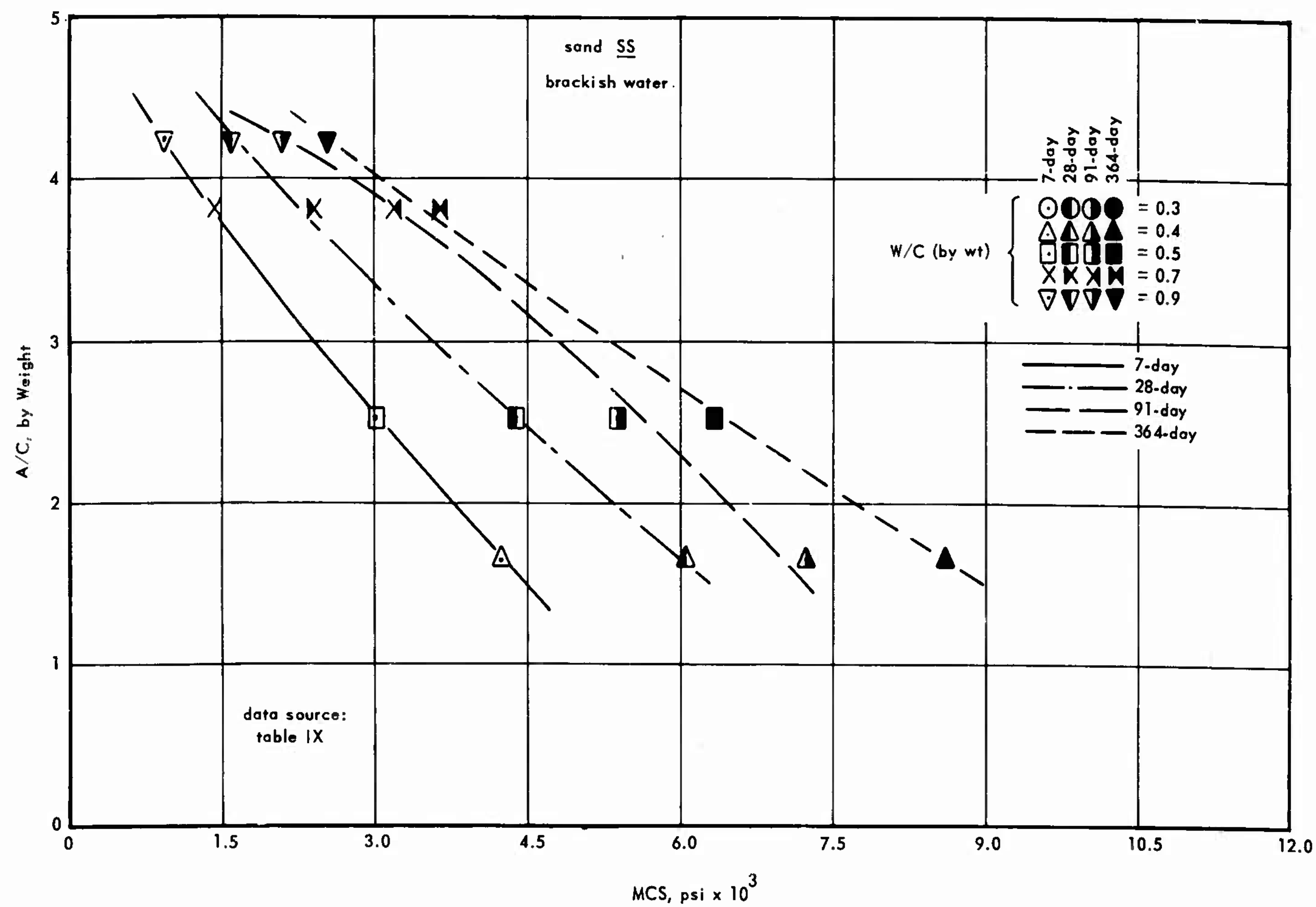

Figure 93. Correlation 8h-c'. (Part 5 of 5)

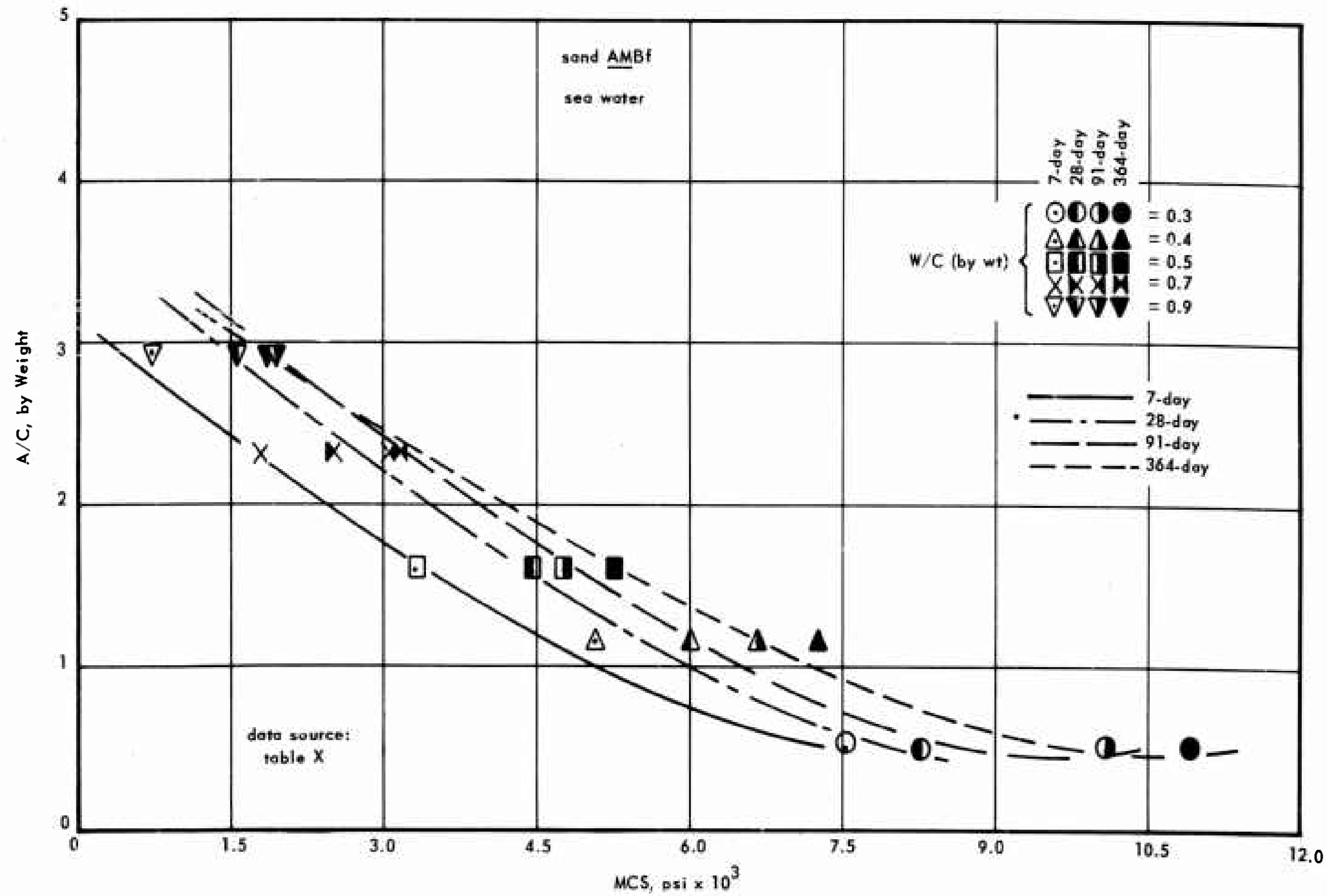

Figure 94. Correlation 8h-c'. (Part 1 of 5)

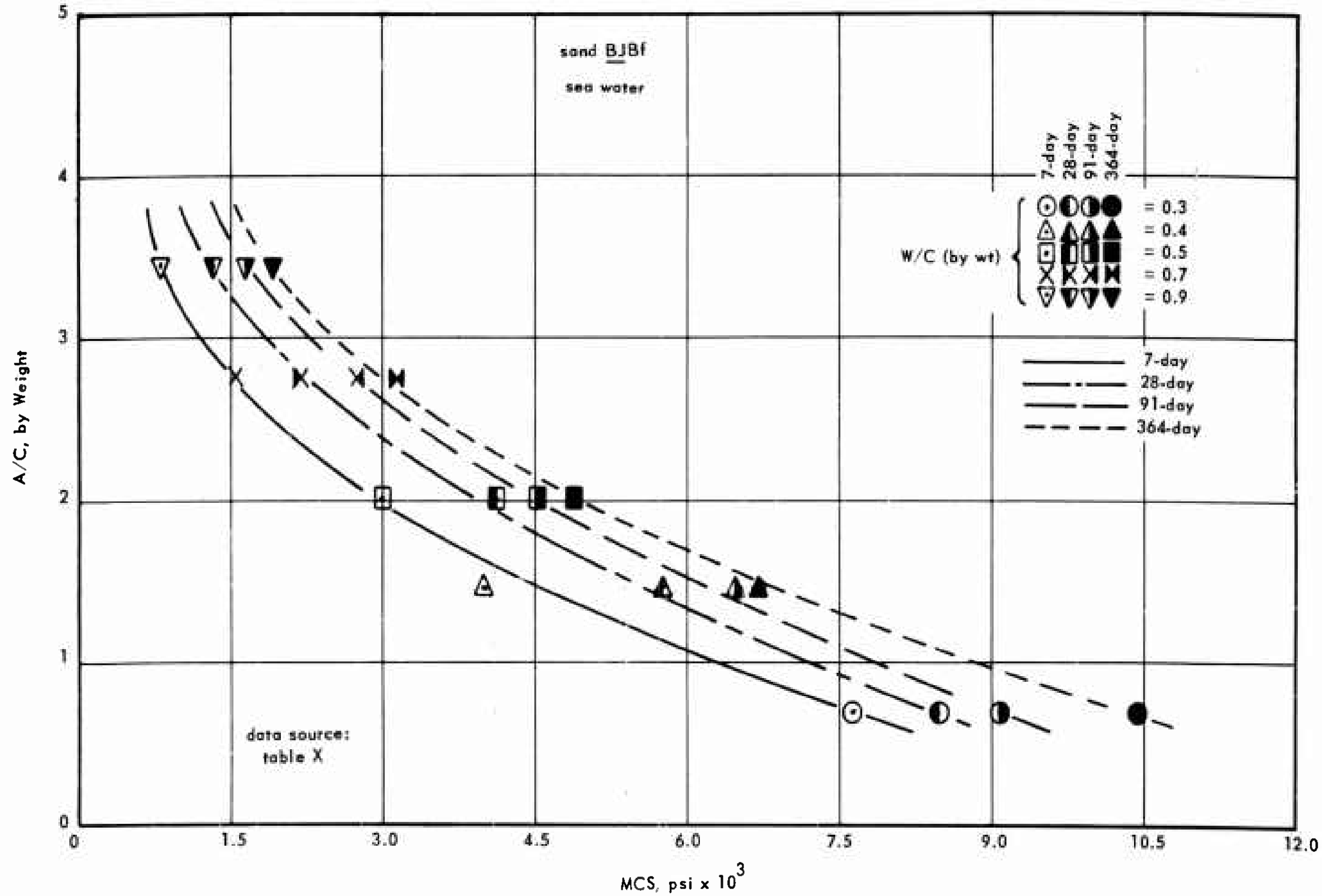

Figure 94. Correlation 8h-c'. (Part 2 of 5)

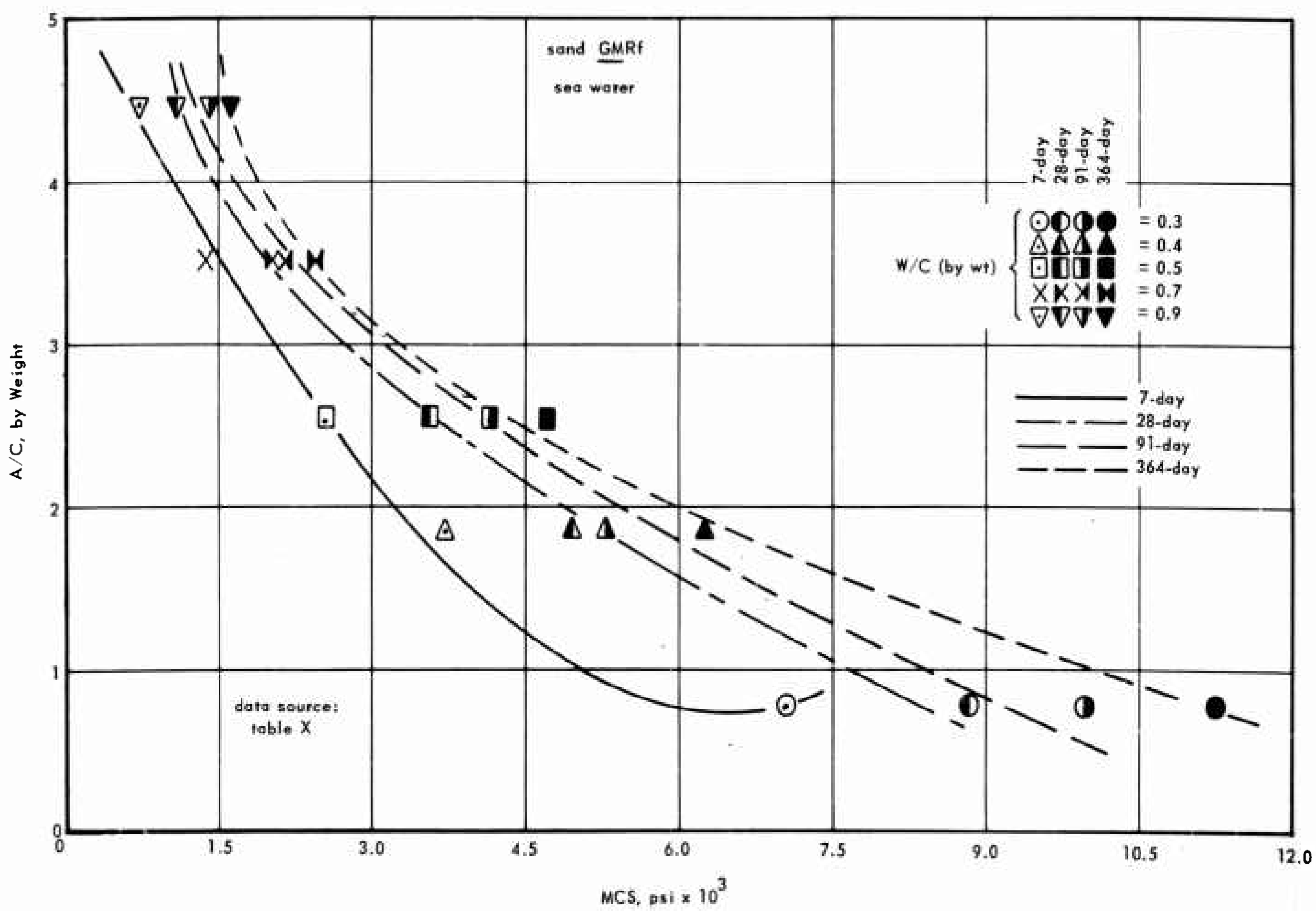

Figure 94. Correlation 8h-c'. (Part 3 of 5)

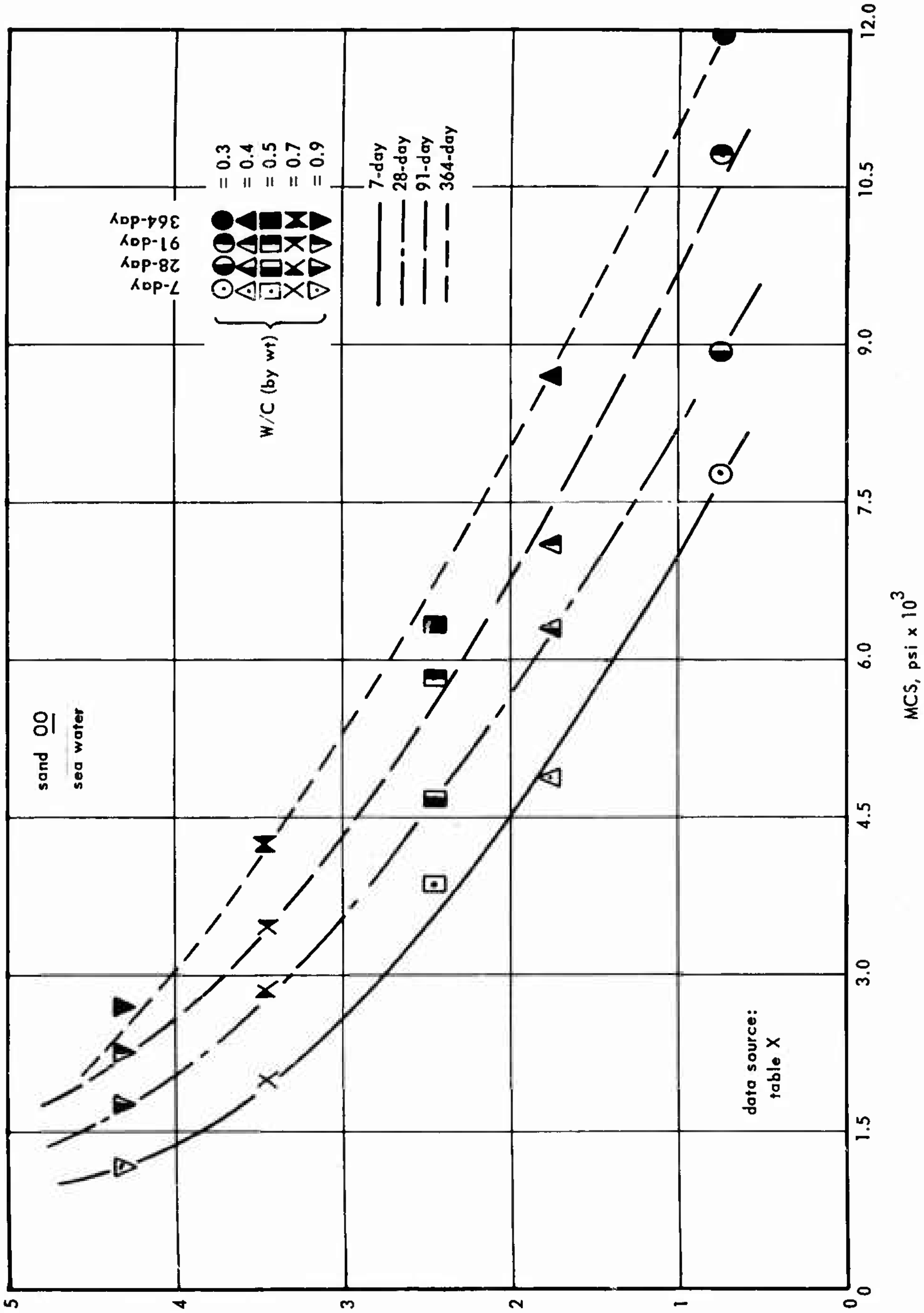

Figure 94. Correlation 8h-c'. (Part 4 of 5)

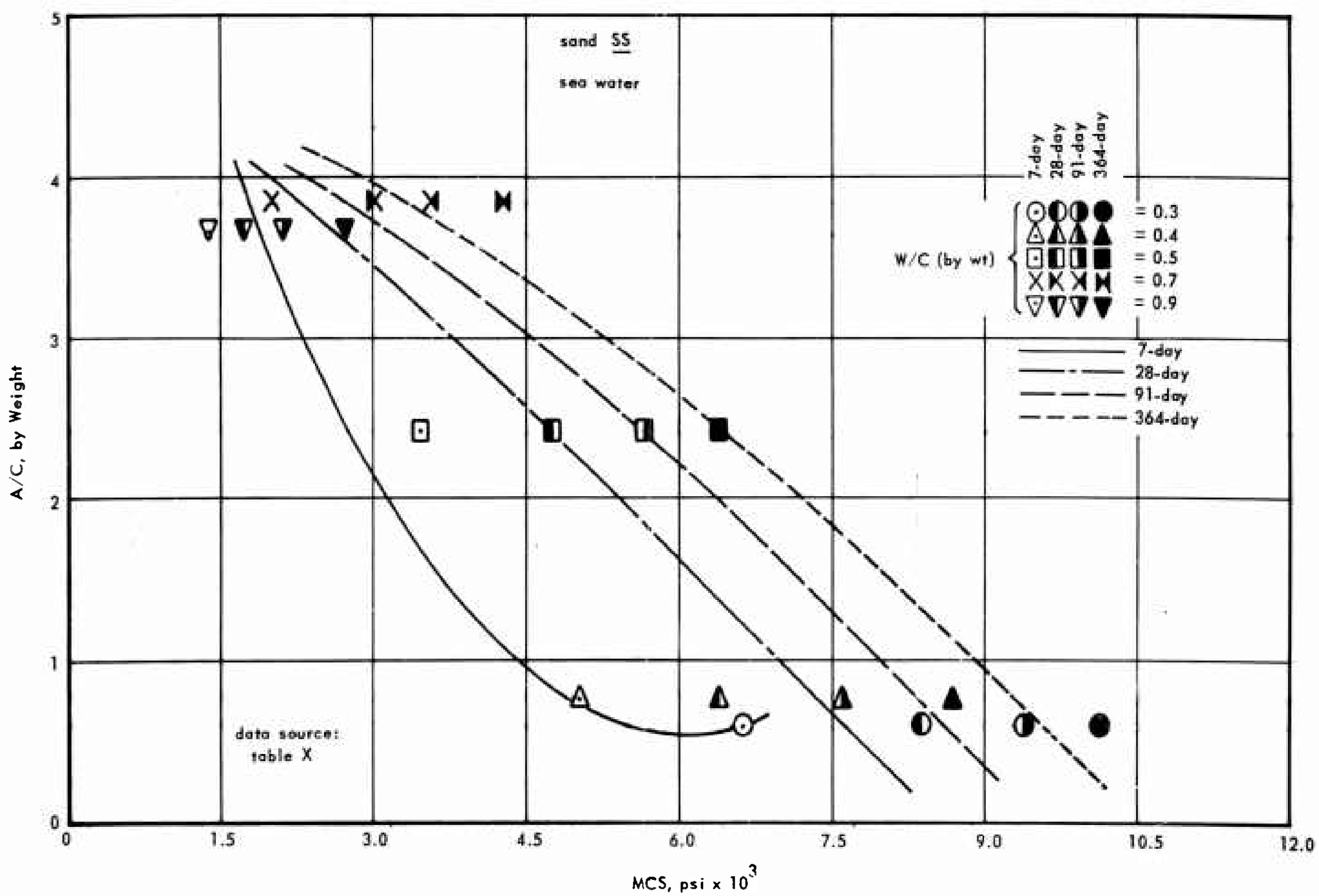

Figure 94. Correlation 8h-c'. (Part 5 of 5)

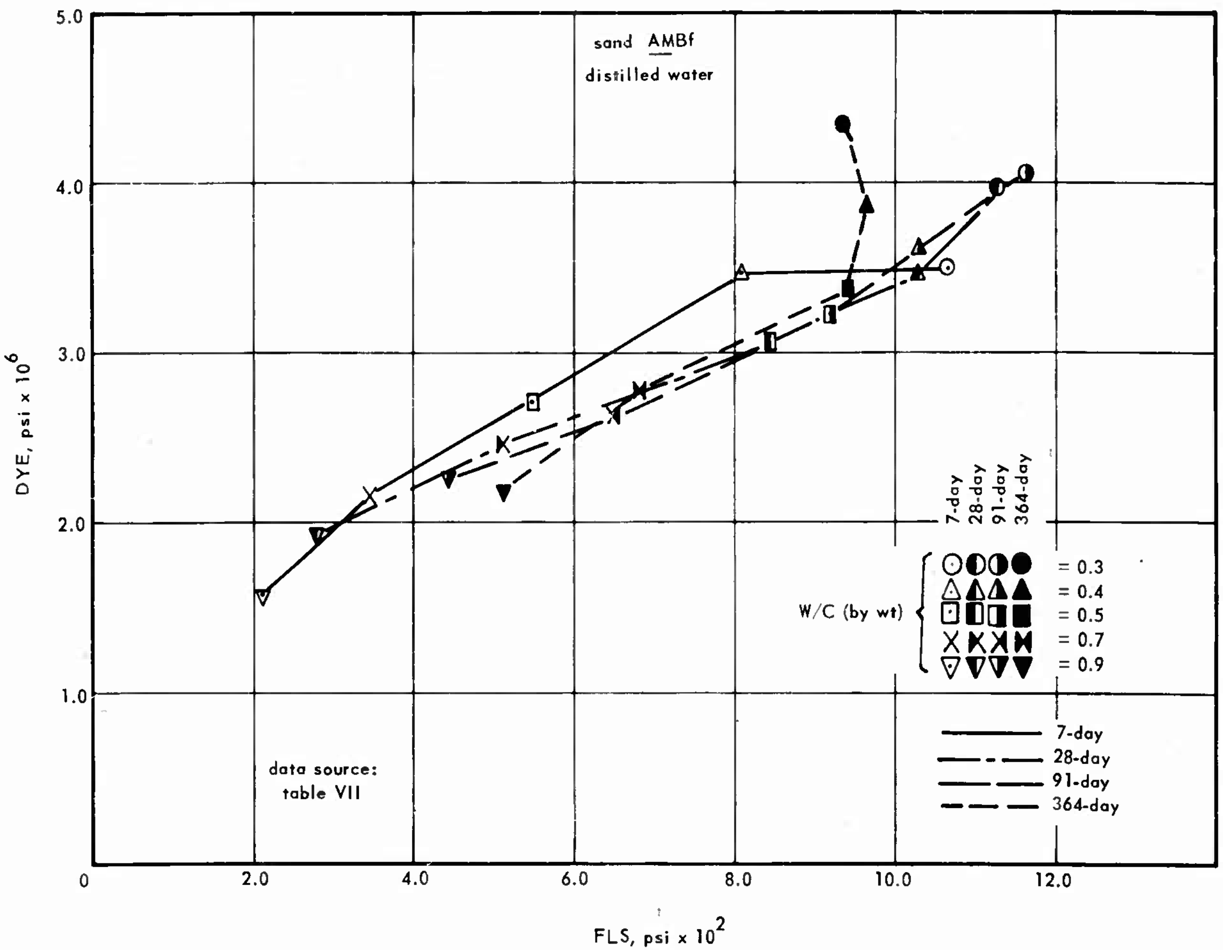

Figure 95. Correlation 9b-a'.

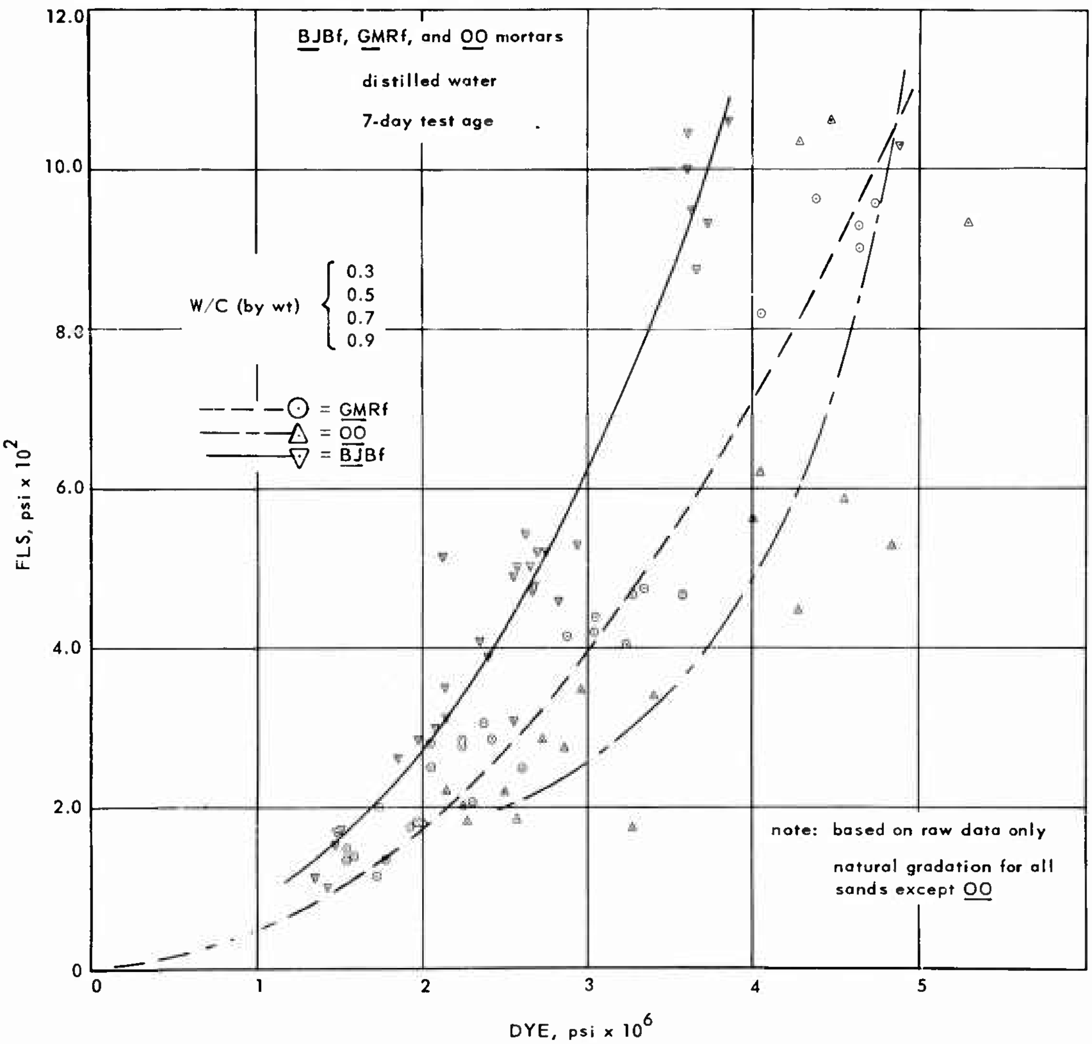

Figure 96. Correlation 9b-a'.

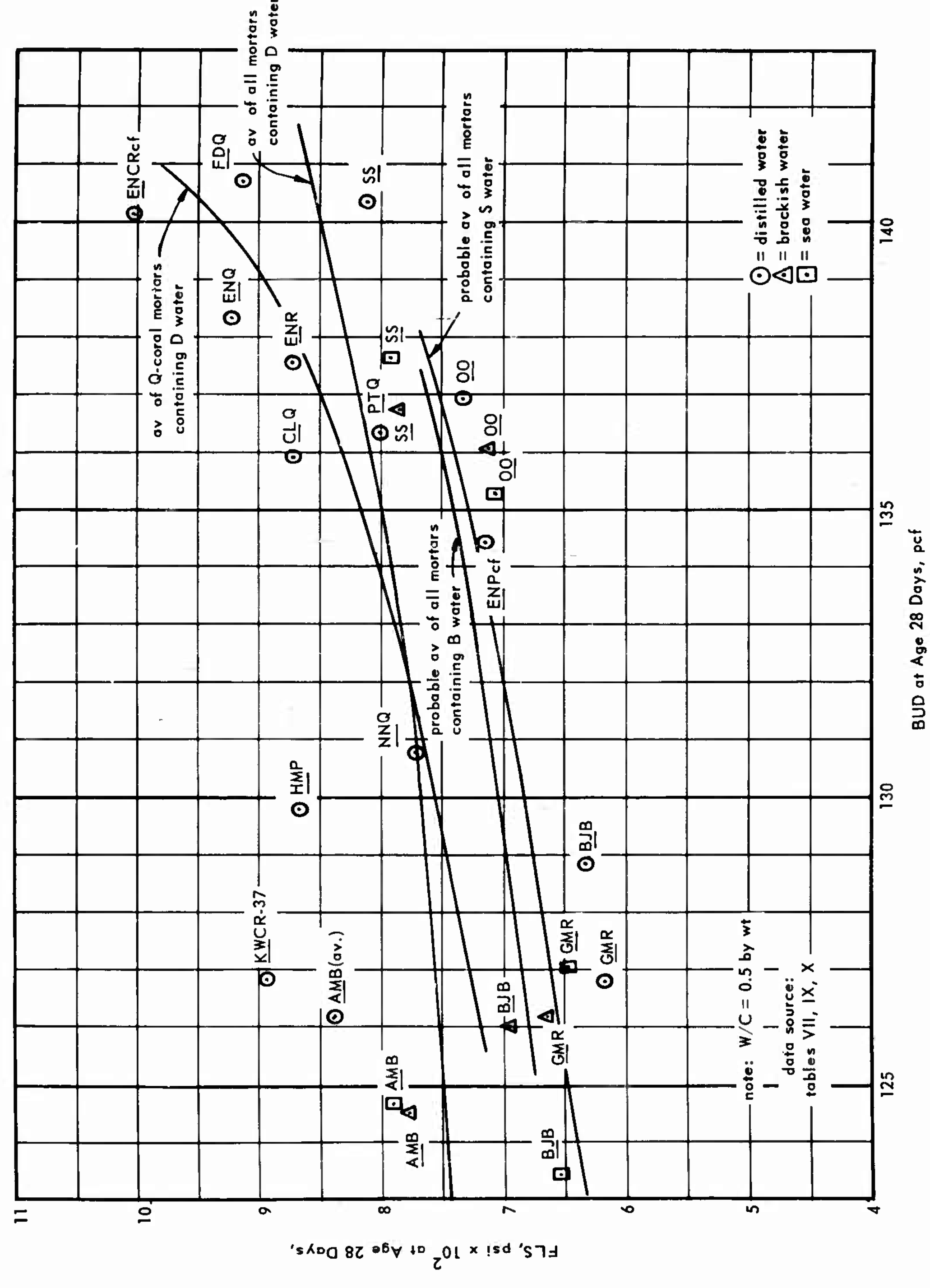

Figure 97. Correlation 9a-b'.

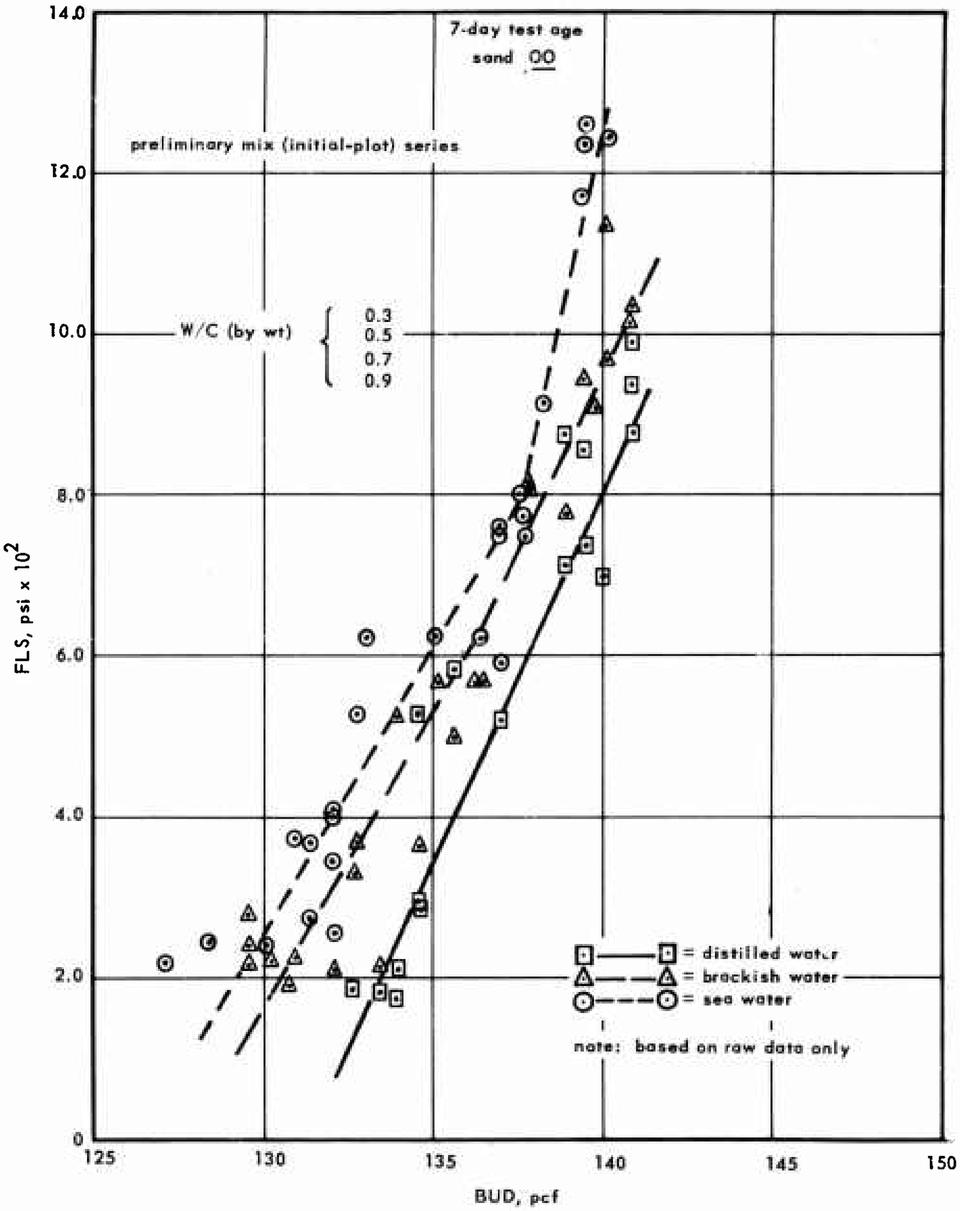

Figure 98. Correlation 9a-b'.

Correlation 9b-b'.

Not applicable.

Correlation 9a-c'.

The average variation of MCS with change in BUD, at age 28 days, is shown in Figure 99. The curve is representative of all mortars, irrespective of water type and sand derivation, and serves as an illustration of the general relationship involved.

Correlation 9b-c'.

The FLS of mortar is related to the MCS in the manner shown in Figures 100 to 104, inclusive. These graphs are typical of the general configuration common to all the mortars investigated in this program. Knowledge of the MCS at age 7 days, for example, permits an estimate of FLS at an equal or greater age. The graphs in Figures 102, 103, and 104 provide fairly reliable values of FLS up to about 800 psi when the age in question is one year or less.

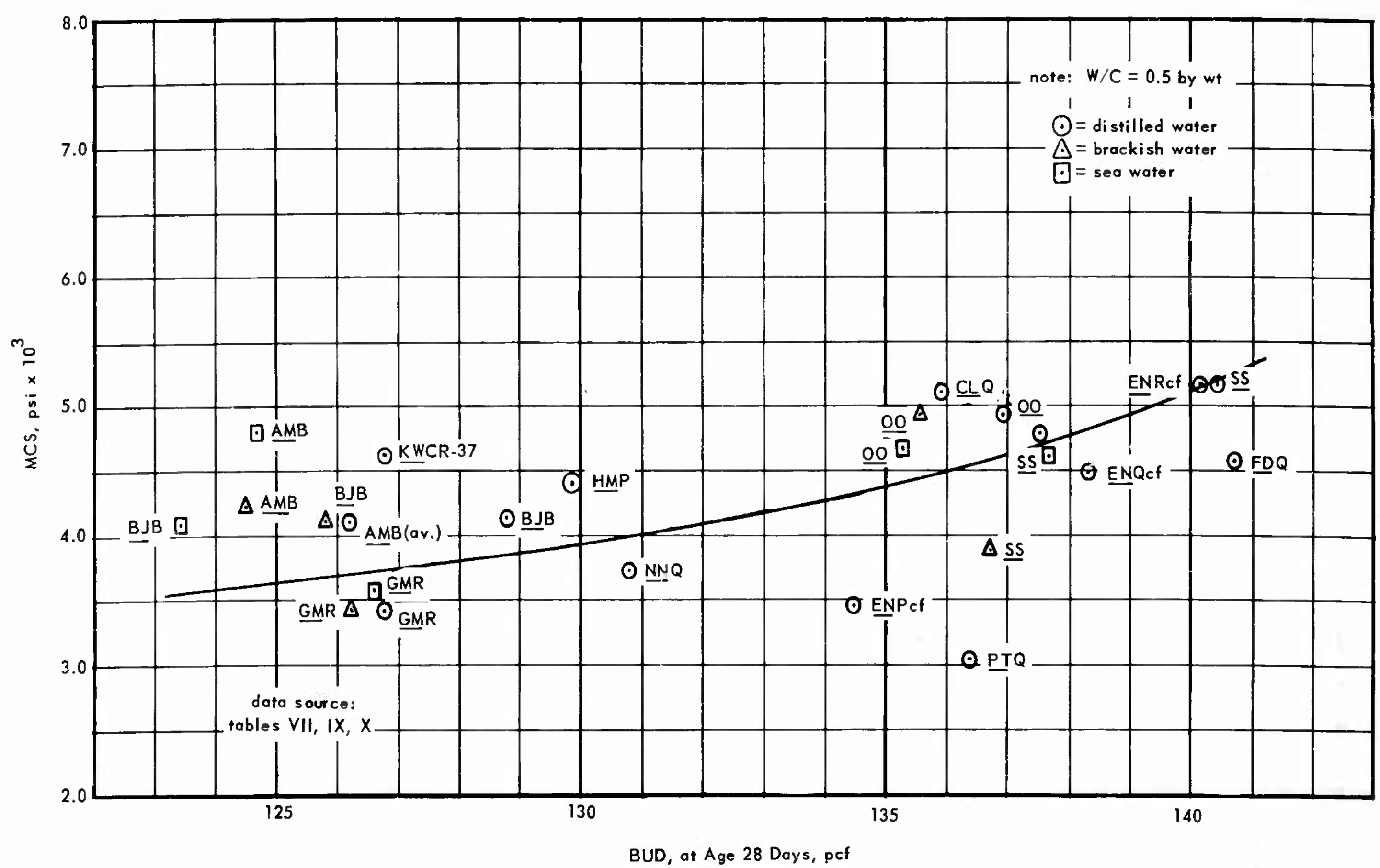

Figure 99. Correlation 9a–c'.

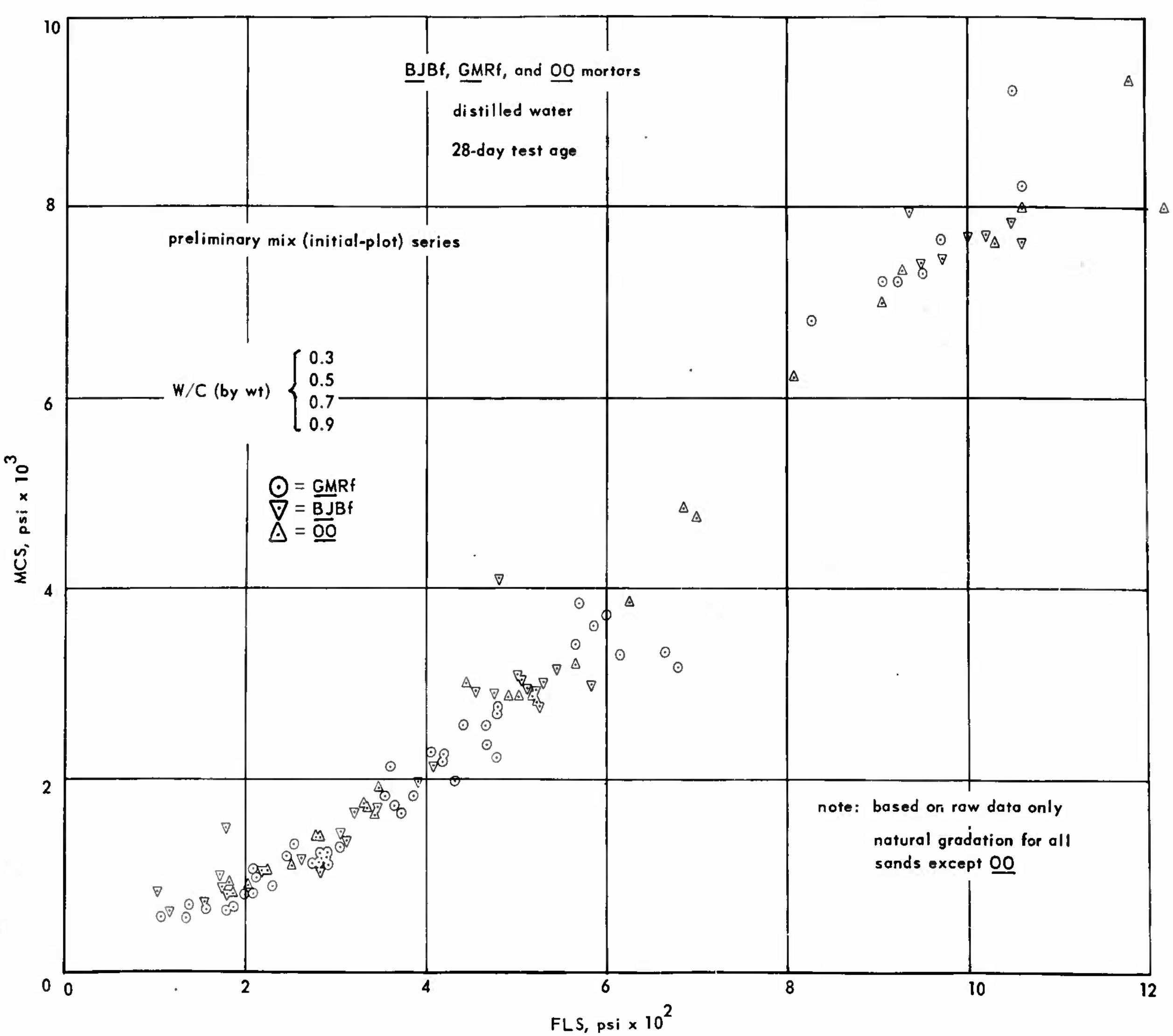

Figure 100. Correlation 9b-c'.

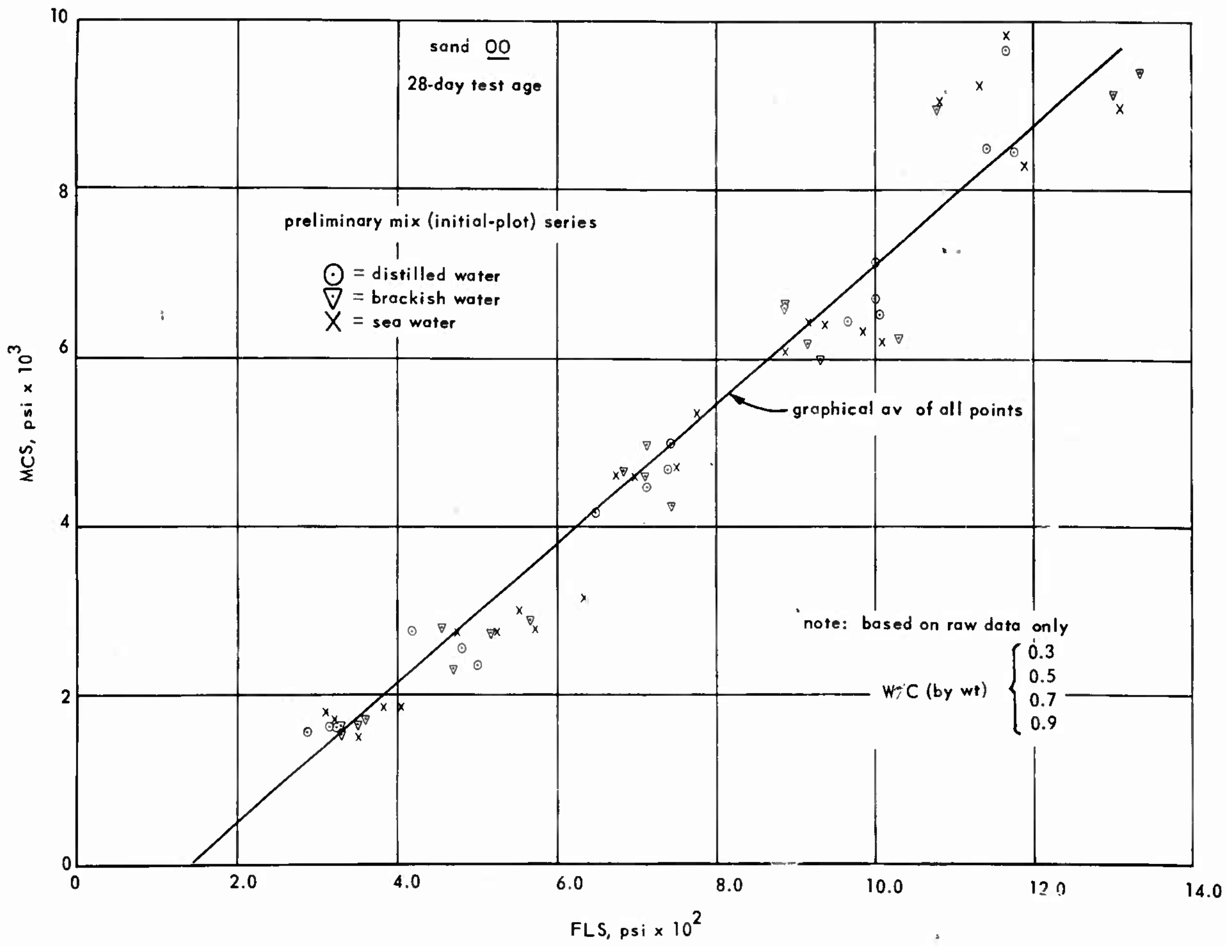

Figure 101. Correlation 9b-c'.

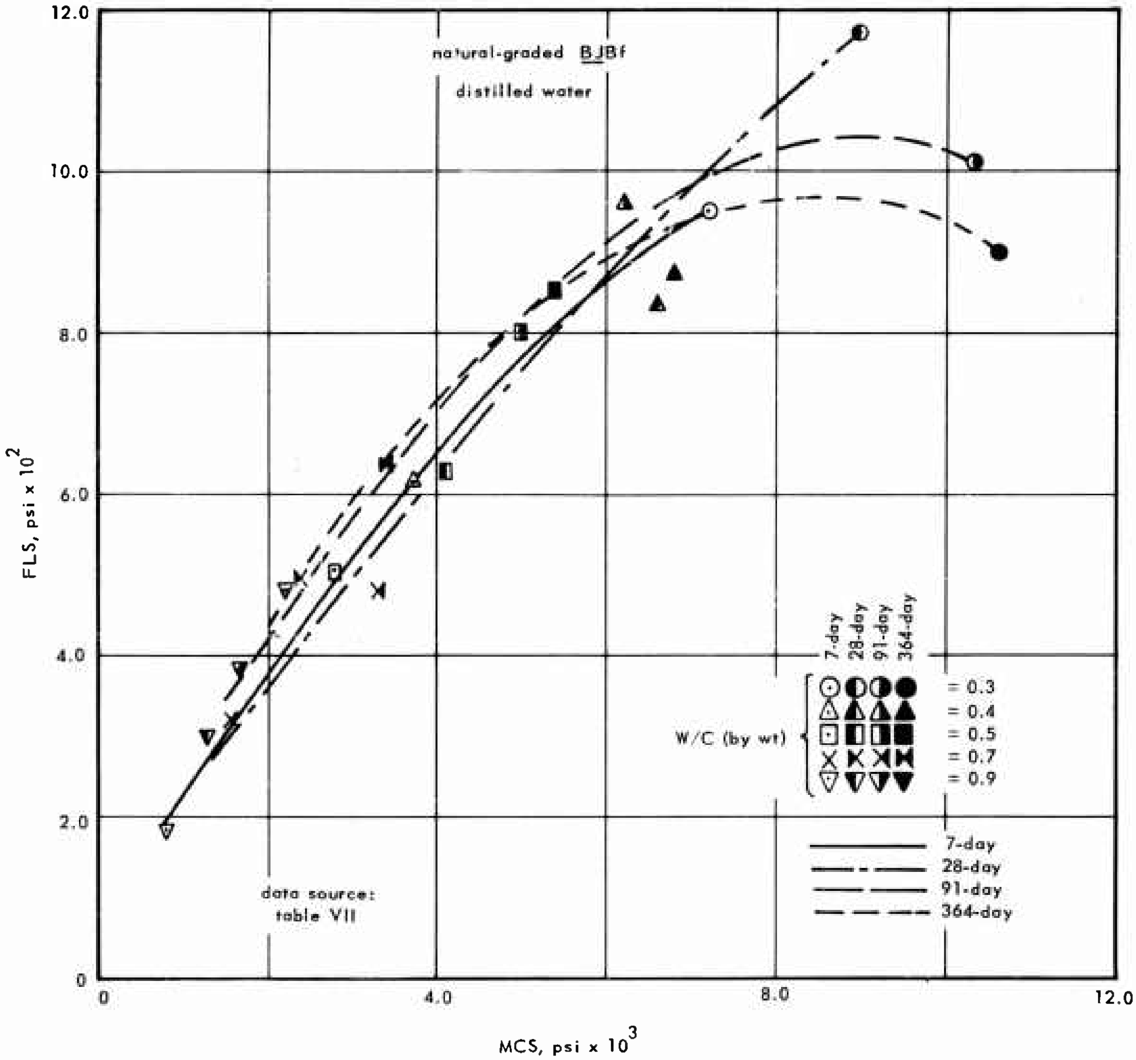

Figure 102. Correlation 9b-c'.

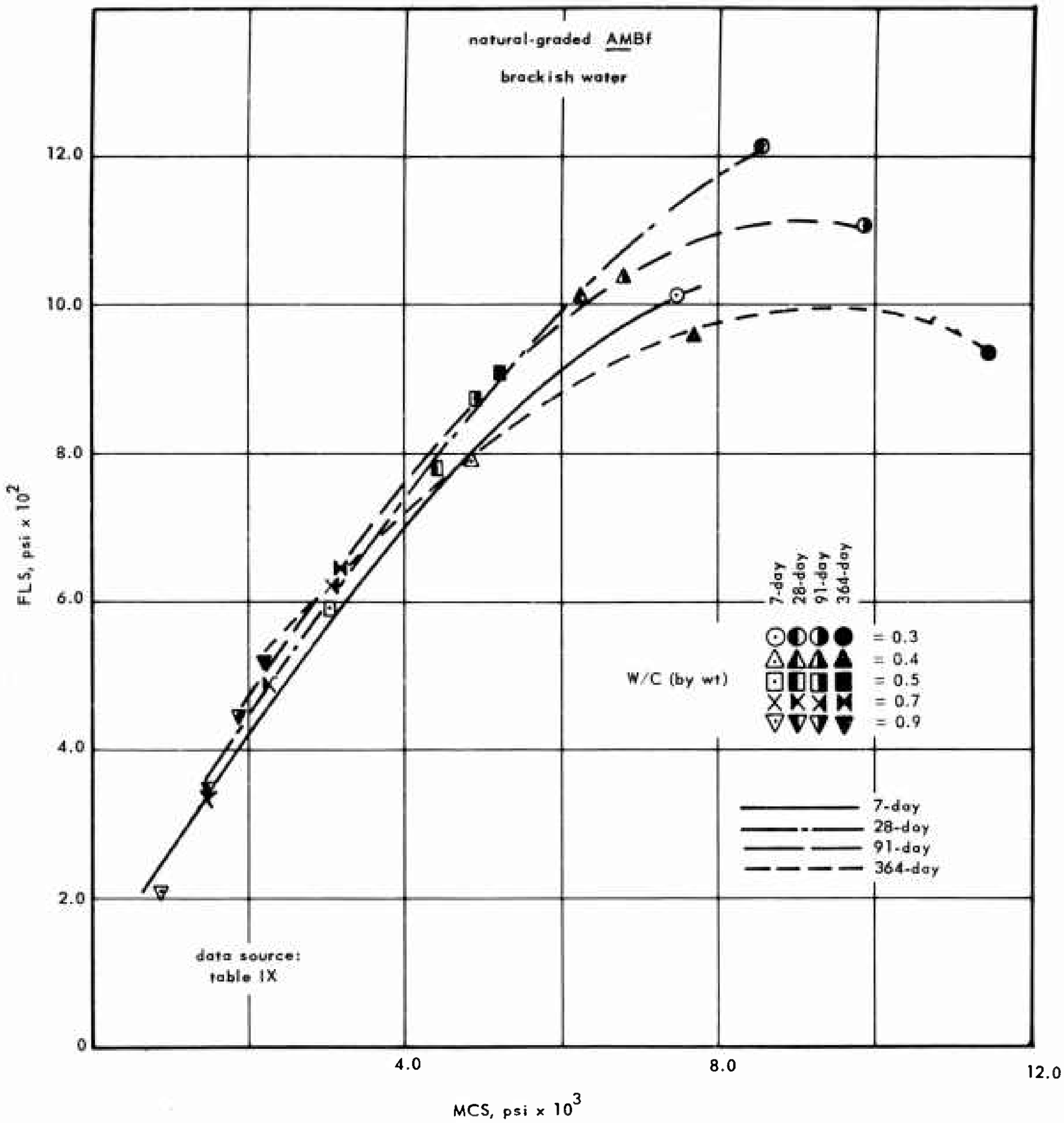

Figure 103. Correlation 9b–c' .

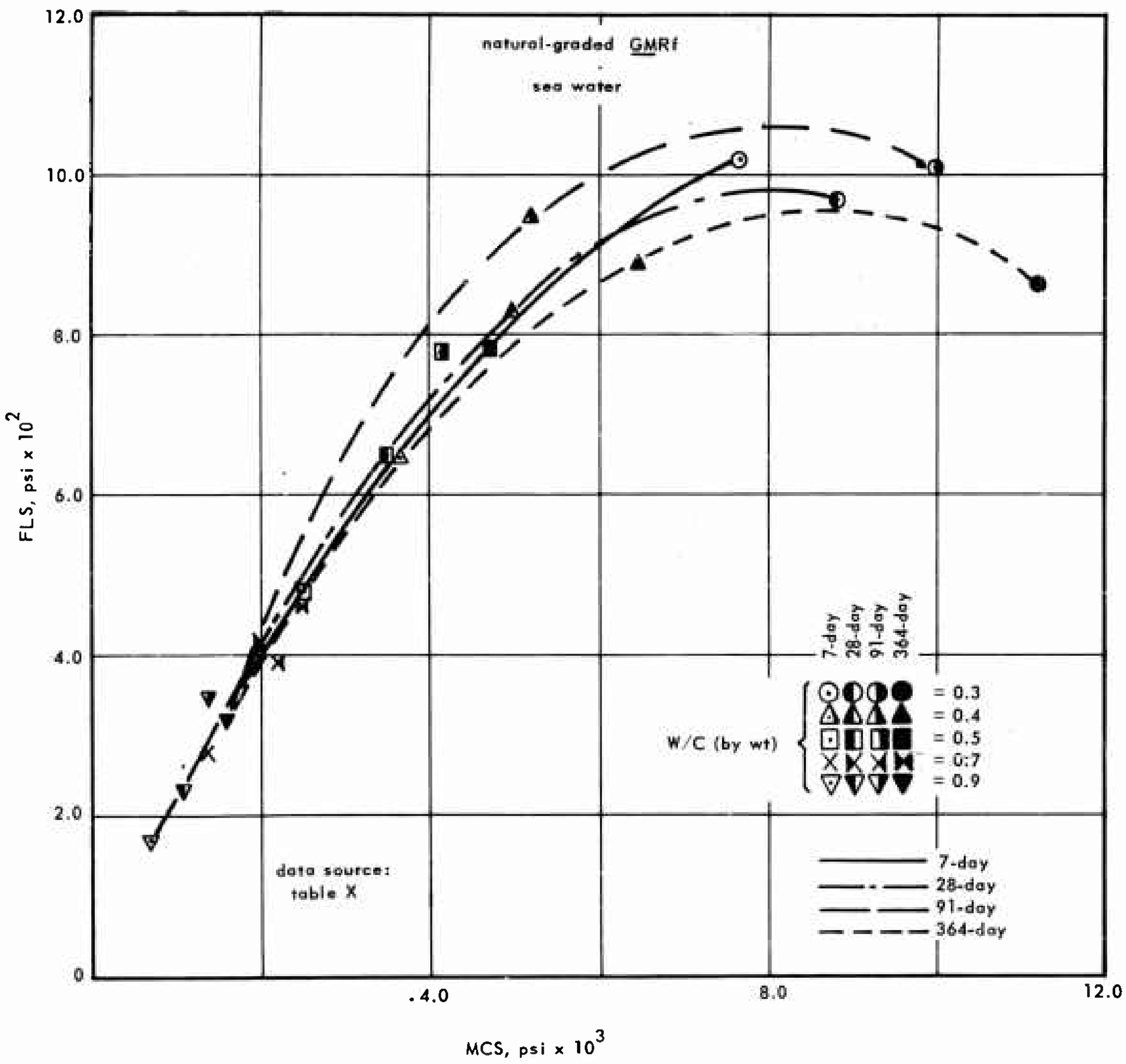

Figure 104. Correlation 9b-c'.

Chapter 8

PRINCIPAL FINDINGS

22. PRELIMINARY CONSIDERATIONS

Based on the graphs shown in Figures 16 to 104, inclusive, the physical properties of coral mortars may be predicted approximately and only when all conditions affecting those properties are known and controllable. The application of laboratory findings, as a means of forecasting the general physical characteristics of mortars fabricated in the field, is perplexing since most variables at the construction site very seldom can be controlled; the accuracy of prediction decreases rapidly with the introduction of unavoidable unknowns. Despite their good intentions, the usual skilled construction workers directly engaged in fabricating and placing coral mortars scarcely are aware of the influential roles played by various physical factors in the attainment of satisfactory structural masonry performance. By virtue of these circumstances some of the physical and personal variables introduced are unlike those in the laboratory and consequently are difficult to compensate for in any attempt at predicting performance of hardened mortar in situ.

23. SUMMARY OF FINDINGS

The following statements constitute the principal findings and hypotheses developed as a result of the tests described in this publication.

(1) The manner in which the unit weight of plastic coral mortar varies with change in fineness modulus of the coral sand is indicated by the water-cement ratio of the mixture.

(2) The influence of water type upon the unit weight of plastic coral mortar is negligible.

(3) The variation of unit weight of plastic coral mortar, with change in percent voids of the coral sand, depends upon the water-cement ratio of the mixture irrespective of the type of water employed.

(4) At low water-cement ratios, the percent air content of the plastic mortar is practically independent of any influence exerted by the derivation of coral sand.

(5) The use of sea water causes variation in percent flow to a degree nearly twice that incident to mortars fabricated with distilled water.

(6) Coral mortars may exhibit less percent flow with increase in percent air content of the plastic mixture.

(7) The yield of coral mortar is independent of sand derivation and water type; and at low water-cement ratios, independent of percent voids in the coral sand.

(8) At low water-cement ratios, the yield of coral mortar is independent of sand derivation, percent voids in the sand, and water type; at high water-cement ratios, the use of reef sand produces higher yield than attainable with beach sand, all other factors being equal and regardless of water type.

(9) The percent air content of mortars fabricated with coral reef sand may serve as a criterion of expected mortar yield.

(10) At low water-cement ratios the use of coral beach sand results in about twice the amount of air content attainable with mortars that incorporate coral reef sand; at high water-cement ratios this tendency is reversed.

(11) Regardless of test age and type of water employed, the bulk density of hardened coral mortar may be predicted on the basis of percent voids in the sand, water-cement ratio, and percent air content of the plastic mortar.

(12) All coral mortars tested, except those containing coral reef sand from Guam and sea water, disclose swelling during the first month of moist storage; of the coral mortars investigated, those incorporating coral reef sand and brackish water exhibit the least swelling-shrinkage tendencies.

(13) For all hardened coral mortars investigated, regardless of sand derivation and water type, with increasing age the smaller the water-cement ratio the less the shrinkage and the greater the water-cement ratio the greater the increase in weight.

(14) Hardened coral mortars tend to exhibit the greatest weight increase if sea water is incorporated in the mix.

(15) The relationship between percent air content of the plastic mortar and subsequent weight-change characteristics of the hardened mortar is dependent upon the coral sand derivation; generally, the use of coral beach sand facilitates relatively great weight-change with increasing percent air content.

(16) For any age not exceeding one year, for any one sand, and for any particular water-cement ratio, the dynamic Young's elastic modulus of coral mortar scarcely is affected by type of water in the mortar mix.

(17) Within the one-year age limitation imposed in this research, the dynamic elastic modulus of coral mortars (containing either distilled or sea water) generally decreases with increase in percent voids of the coral sand, irrespective of water-cement ratio.

(18) The dynamic elastic modulus of coral mortar usually decreases with increase in confined crushing strength of the coral sand, all other things being equal.

(19) Within the one-year age limitation imposed, regardless of water type and regardless of whether reef or beach sands are used, for the mortar mixes investigated the approximate median dynamic elastic moduli of coral mortars is 3,000,000 psi, whereas the median for companion mortars incorporating Ottawa sand is about 4,000,000 psi.

(20) At low water-cement ratios, involving distilled or brackish water, increased percent flow of the plastic coral mortar reflects an increased dynamic elastic modulus of the hardened mortar; the substitution of sea water in the mix causes increased percent flow to reflect a decrease in dynamic elastic modulus.

(21) In general, the dynamic elastic modulus of hardened coral mortars (incorporating distilled water and any derivation of coral sand) decreases at a rate of about 5 percent with each 1-percent increase in air content of the plastic mortars; all other factors being equal, the use of brackish or sea water changes the rate of decreasing modulus to 20 or 30 percent, respectively.

(22) At low water-cement ratios the rupture moduli of all coral mortars made with sea water decrease appreciably with increasing age.

(23) At intermediate water-cement ratios the rupture moduli of mortars containing quarry coral sand tend to increase with increasing age.

(24) The rate at which the rupture modulus of one-month-old coral mortar decreases with rising percent sand voids is ten times as fast when natural-graded bank-run or quarry sands are incorporated in the mix as when natural-graded reef or beach coral sands are so employed.

(25) At intermediate water-cement ratios, the rupture modulus of coral mortar is highest if the fine aggregate is ideal-graded coral reef sand.

(26) The rupture modulus and compressive strength of one-month-old coral mortar fabricated with ideal-graded coral reef sand increases about 25 percent as the predominant shape of the sand particles changes from subround to angular, all other things being equal.

(27) The use of the confined crushing strength of coral sand, as a criterion for predicting the magnitude of rupture modulus peculiar to coral mortar fabricated with that sand, may be practicable only with respect to coral beach sands.

(28) At low water-cement ratios the rupture modulus of coral mortar at any age not exceeding one year, regardless of water type and sand derivation, may be as much as five times the modulus of coral mortar having a high water-cement ratio.

(29) The change in magnitude of rupture modulus of coral mortar, with increase in aggregate-cement ratio, is smallest if the mortar is fabricated with quarry coral sand.

(30) Within the one-year age limitation observed, the compressive strength of any coral mortar generally increases with age regardless of water type employed in the mix.

(31) The order of magnitude of the compressive strength of coral mortar is not notably influenced by the derivation of coral sand, provided the natural gradation of the sand is not altered.

(32) An increasing percent of sand voids causes a decrease in compressive strength of coral mortar, all other things being equal; the rate of such reduction in compressive strength is related to the derivation of the coral sand under consideration.

(33) Regardless of coral sand derivation, water type, and age (within the imposed one-year limitation), the compressive strength values of all coral mortars increase as the water-cement ratio decreases.

(34) The change in compressive strength, with increasing aggregate-cement ratio, is smallest if the coral mortar contains beach or bank-run sand.

(35) The rupture modulus and compressive strength of hardened coral mortar decrease with increase in percent air content observed with the plastic mortar.

(36) Generally, a rise in bulk density or rupture modulus of the hardened coral mortar reflects an increase in the dynamic elastic modulus and compressive strength of the mortar at the same age; and the higher the rupture modulus, the higher the bulk density.

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APPENDIX I

THEORIES CONCERNING IDEAL GRADATION OF AGGREGATE

The Fuller-Thompson ideal curve for dense gradation is empirical; in essence it is a curve-fitting operation used in proportioning a mortar or concrete mixture for maximum density. The gradation curve is designed by fitting either a parabola or an ellipse to a tangent at the point where the aggregate fraction is one-tenth of the maximum sized fraction. The equations are as follows:

for the ellipse, $(y-7)^2 = (b^2 \div a^2)(2ax-x^2)$;

for the tangent, $y = [(100-y_1) \div (D-x_1)] \ (x-x_1) + (y_1)$;

for the parabola, $y = (7) + 100(bx)^{1/2}$;

where a and b = horizontal and vertical axes, respectively, of either ellipse or parabola,

D = diameter (in.) of maximum particle size,

y = percentage (by weight) smaller than the given diameter,

and x = diameter (in.).

The elliptic or parabolic portion of the curve encompasses the sand portion of concrete mixes and the tangent pertains to the coarse portion; Figure 105 is a reproduction[17] of Figure 8 in the paper[7] by Fuller and Thompson. The major and minor axes of the ellipse are determined empirically by a complicated procedure which is described fully in the Fuller-Thompson reference cited. Housel[18] has shown that this is a curve-fitting method for a particular aggregate rather than a rational method of mix design; he has shown, too, that this curve closely approximates Weymouth's curve, as is apparent in Figure 106. Valid reasons have been stated by Hool and Kinne[19] to show why mixes based upon the Fuller-Thompson curve invariably are deficient in fines and thus require larger amounts of sand than indicated by the curve. For gradations obtained in accordance with the Fuller-Thompson method, the mixes are harsh generally and so are relatively poor in workability as a result of a scarcity of fine particles; in some instances they have been known to be dense and to exhibit low porosity.

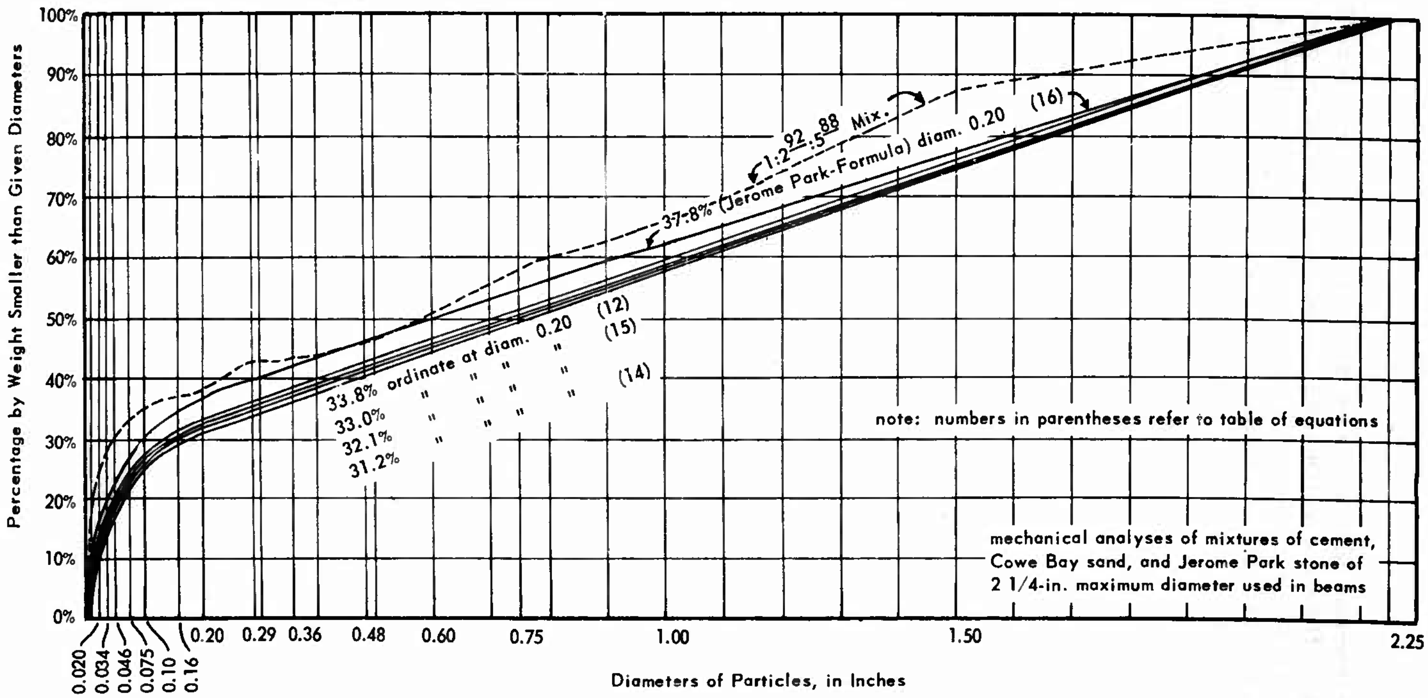

Figure 105. Fuller-Thompson ideal gradation curves (maximum density) for a particular concrete mixture.

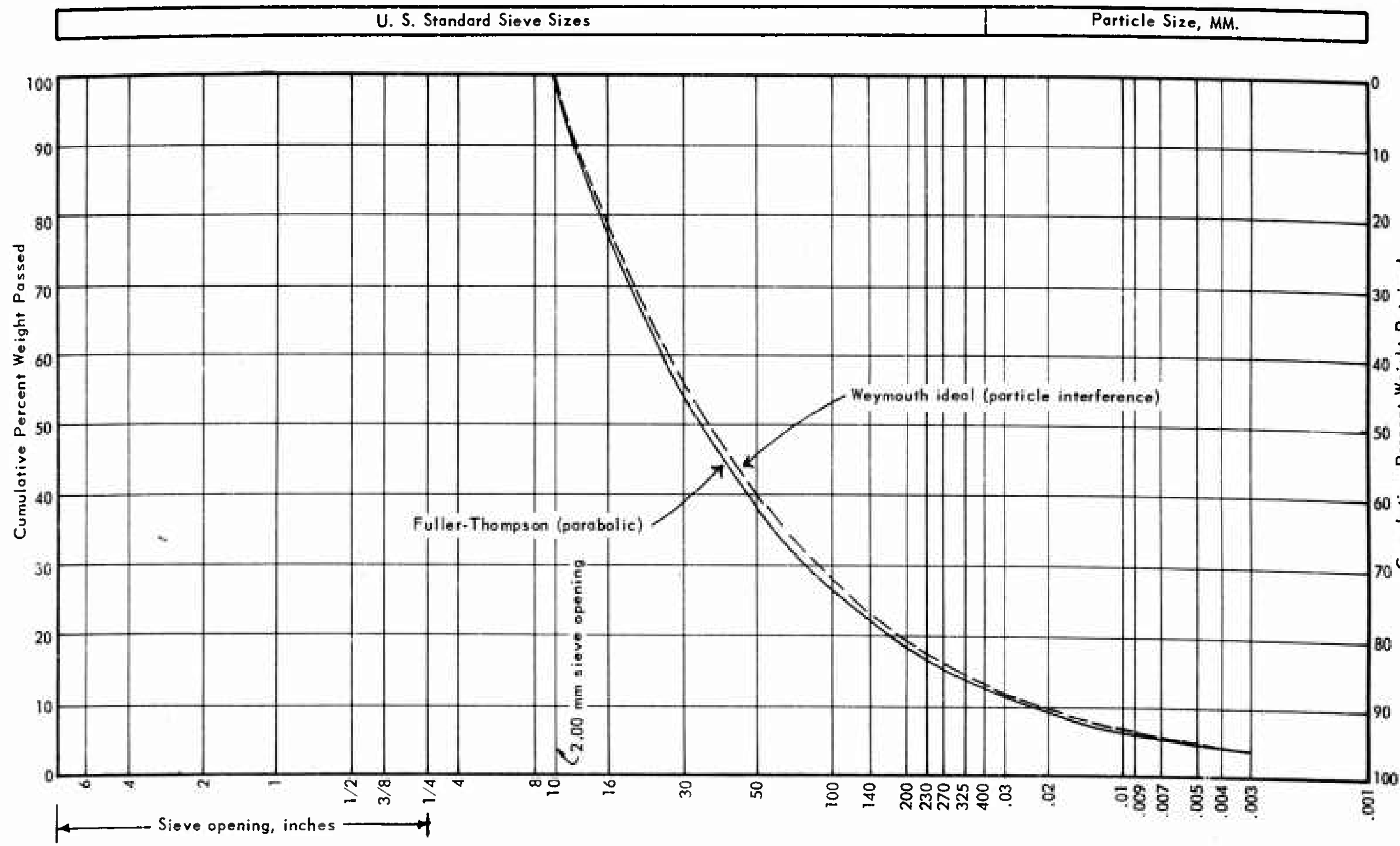

Figure 106. Weymouth theoretical curve versus Fuller-Thompson empirical curve when maximum particle size is 2 mm.

Talbot's curve[8*] entails a simple method of designing the PLUS 4 portion of the mix but is not adaptable to the MINUS 4 portion because of the structure of the equation, which is stated as follows:

$$P = 100 \, [(d)^{1/2} - (0.187)^{1/2}] \div [(D)^{1/2} - (0.187)^{1/2}] \, ;$$

where P = cumulative percentage passing the size in question,

D = maximum size (in.) of aggregate,

d = sieve opening (in.),

and 0.187 = sieve opening (in.) Size 4 in Tyler Sieve Series.

As the equation is not solvable for particles smaller than Size 4 in the U. S. Sieve Series, it is of no benefit in proportioning coral sands for use in mortars.

Weymouth's ideal curve method is based upon his theory of particle interference and provides for minimizing the interference of larger particles upon those smaller particles that tend to fill the voids. The equation of the curve lends itself to analysis since it may be developed on the basis of density of each size fraction or on the basis of an arbitrary particle shape. Weymouth's ideal continuous grading is described by the following equation, which is valid for materials in the dry rodded condition:

$$t = (D) \, [(d_o \div d_a)^{1/3} - (1)]$$

where t = average clear distance between adjacent particles within the size fraction under consideration,

D = mean particle diameter (mm) of largest size fraction,

d_o = density (i.e., degree of concentration of the aggregation of particles in any size group) while in dry rodded condition and measured directly as an empirical quantity equal to the quotient of absolute volume divided by unit bulk volume available in the size group under consideration,

*This reference contains no comments regarding the gradation curve; the paper emphasizes effect of natural voids rather than how to minimize void content by changes in gradation. See Reference 20 for details concerning Talbot's equation and curve.

and d_a = actual density (i.e., absolute volume per volume available for the size fraction under consideration) relative to the density, d_o, while in dry rodded condition.

A constant distance between particles is obtained only when d_a is kept in a fixed ratio to the d_o value. Using the U. S. Sieve Series with a constant sieve opening ratio of 2:1, the distance is

$$t = D_1 = \text{diameter of next smaller size fraction,}$$

or $$D_1 \div D = 1/2,$$

whence $$d_a = (0.296)\,(d_o).$$

If all size fractions are assumed to be of equal density d_o, theoretical curves for spherical particles may be computed as shown in Table XVII and drawn as illustrated in Figures 106 and 107.

Construction of the curve for the actual particles corresponding to any coral sand under consideration for use as mortar entails measurement of d_o and thence plotting a continuous gradation for that particular sand. The Weymouth method also may be used for both fine and coarse fractions of the aggregates in concrete; the gradation may be analyzed readily by the mechanics involved.

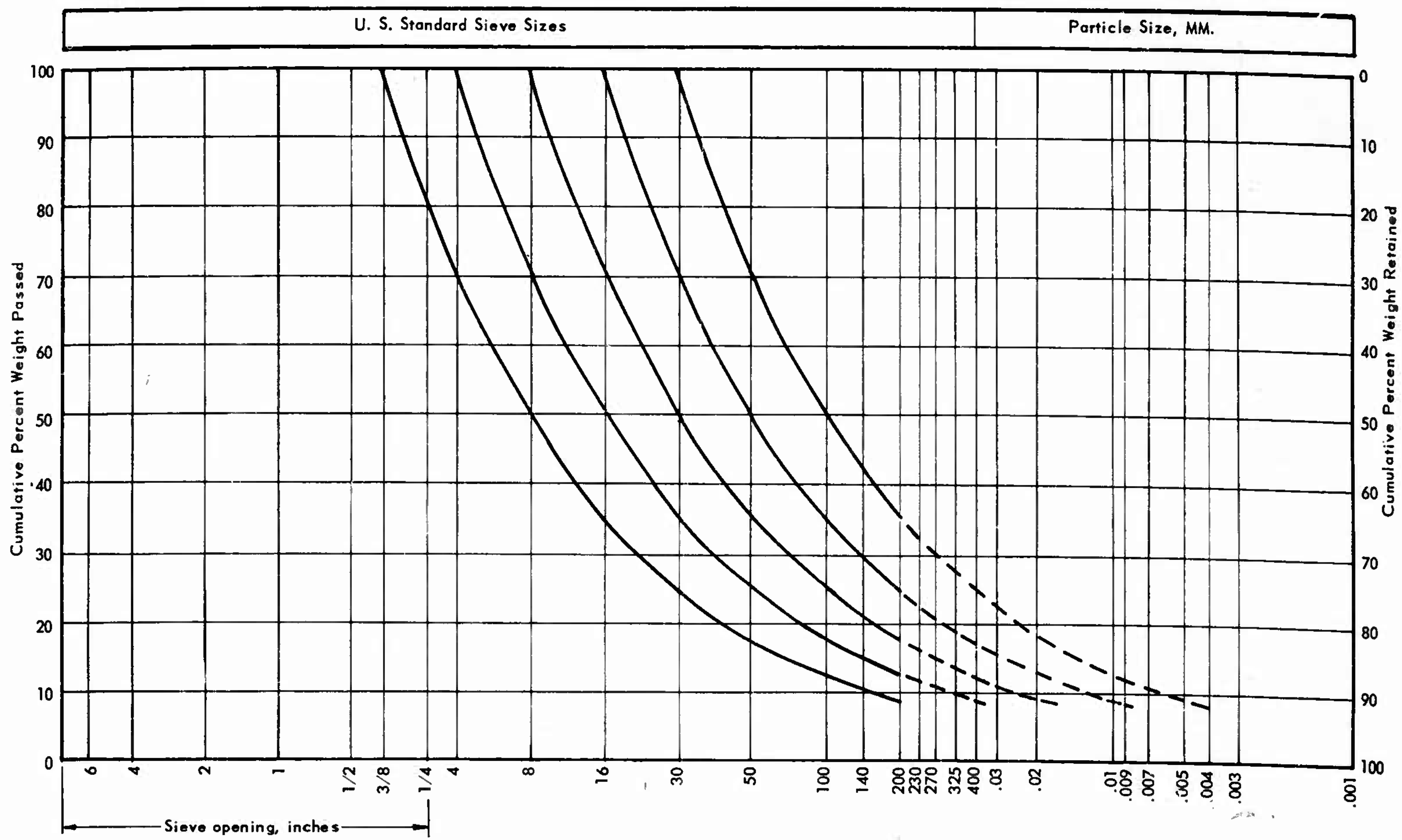

Figure 107. Weymouth ideal gradation curves (minimum particle interference) for selected maximum spherical particle sizes.

Table XVII. Mechanical Analyses of Size Distri

U. S. Sieve Series		Maximum Size of Particle = 0.375 in.		
Sieve Number	Sieve Opening, mm	V_n	$v_n = (V_n)\ (d_a)$	Cum % Retained
4	4.76	V_1 = unity = 1.000	$v_1 = (1.000)\ (0.296) = 0.296$	29.6
8	2.38	$V_2 = (V_1) - (v_1) = 0.704$	$v_2 = (0.704)\ (0.296) = 0.208$	50.4
16	1.19	$V_3 = (V_2) - (v_2) = 0.496$	$v_3 = (0.496)\ (0.296) = 0.147$	65.1
30	0.59	$V_4 = (V_3) - (v_3) = 0.349$	$v_4 = (0.349)\ (0.296) = 0.103$	75.4
50	0.297	$V_5 = (V_4) - (v_4) = 0.246$	$v_5 = (0.246)\ (0.296) = 0.073$	82.7
100	0.149	$v_6 = (V_5) - (v_5) = 0.173$	$v_6 = (0.173)\ (0.296) = 0.051$	87.8
*200	0.074	$V_7 = (V_6) - (v_6) = 0.122$	$v_7 = (0.122)\ (0.296) = 0.036$	91.4
*Pan	--	--- --- ---	--- --- --- ---	100.0
				FM = 3.91

Note: V_n = Volume of space available to that particle size group which is the mean of two sie

v_n = Volume occupied by that size group lying between indicated sieve number and next s

Values of cumulative percentage retained reflect those indicated by appropriate curves

*Not used in computing FM.

1

Table XVII. Mechanical Analyses of Size Distributions in Ideal-Graded Spherical Particle Aggregations

m Size of Particle = 0.375 in.		Max Size = #4 = 0.187 in.			Max Size = #8 = 0.0937 in.			Max Size
$v_n = (V_n)(d_a)$	Cum % Retained	V_n	v_n	Cum % Retained	V_n	v_n	Cum % Retained	V_n
v_1 = (1.000) (0.296) = 0.296	29.6	--	--	--	--	--	--	--
v_2 = (0.704) (0.296) = 0.208	50.4	1.000	0.296	29.6	--	--	--	--
v_3 = (0.496) (0.296) = 0.147	65.1	0.704	0.208	50.4	1.000	0.296	29.6	--
v_4 = (0.349) (0.296) = 0.103	75.4	0.496	0.147	65.1	0.704	0.208	50.4	1.000
v_5 = (0.246) (0.296) = 0.073	82.7	0.349	0.103	75.4	0.496	0.147	65.1	0.704
v_6 = (0.173) (0.296) = 0.051	87.8	0.246	0.073	82.7	0.349	0.103	75.4	0.496
v_7 = (0.122) (0.296) = 0.036	91.4	0.173	0.051	87.8	0.246	0.073	82.7	0.349
--- --- --- ---	100.0	--	--	100.0	--	--	100.0	--
	FM = 3.91			FM = 3.03			FM = 2.20	

t particle size group which is the mean of two sieve sizes, shown in U. S. Sieve Series column, between which the

ip lying between indicated sieve number and next smaller sieve number.

hed reflect those indicated by appropriate curves in Figure 107.

2

-Graded Spherical Particle Aggregations

.187 in.	Max Size = #8 = 0.0937 in.			Max Size = #16 = 0.0469 in.			Max Size = #30 = 0.0232 in.		
Cum % Retained	V_n	v_n	Cum % Retained	V_n	v_n	Cum % Retained	V_n	v_n	Cum % Retained
--	--	--	--	--	--	--	--	--	--
29.6	--	--	--	--	--	--	--	--	--
50.4	1.000	0.296	29.6	--	--	--	--	--	--
65.1	0.704	0.208	50.4	1.000	0.296	29.6	--	--	--
75.4	0.496	0.147	65.1	0.704	0.208	50.4	1.000	0.296	29.6
82.7	0.349	0.103	75.4	0.496	0.147	65.1	0.704	0.208	50.4
87.8	0.246	0.073	82.7	0.349	0.103	75.4	0.496	0.147	65.1
100.0	--	--	100.0	--	--	100.0	--	--	100.0
= 3.03	FM = 2.20			FM = 1.45			FM = 0.80		

in U. S. Sieve Series column, between which the size group lies.

ber.

APPENDIX II

PRINCIPLES OF MEASURING AIR CONTENT OF MORTAR

In the following explanation of the principles involved in measuring air content, let V be the total volume of mortar or 400.0 ml, γ_w the apparent specific gravity of the mixing water, γ_c the apparent specific gravity of the cement, γ_s the apparent specific gravity of the sand, and W the total weight of V:

$$V = \left\{ \begin{array}{c c} & V_o \\ \text{Volumes of} & V_1 \\ \text{constituents} & V_2 \\ & V_3 \end{array} \right. \begin{array}{|c|} \hline \text{air} \\ \hline \text{water} \\ \hline \text{cement} \\ \hline \text{sand} \\ \hline \end{array} \left. \begin{array}{c c} \text{zero} & \\ W_1 & \text{Weights of} \\ W_2 & \text{constituents} \\ W_3 & \end{array} \right\} = W$$

The experimental (actual) density* of the mortar in the plastic state is denoted by w_a and is equal to $(W \div V)$ gm per ml. The theoretical density (i.e., when the air content is zero) is w_t and is equal to $[(W) \div (V_1 + V_2 + V_3)]$ gm per ml. The percentage of entrained air is equal to $(V_o \div V)(100)$. However,

$$V_1 = (W_1 \div \gamma w)\text{ ml} = [(W_1) \div (62.29)(\gamma w)] \text{ cu ft,}$$

$$V_2 = (W_2 \div \gamma c)\text{ ml} = [(W_2) \div (62.29)(\gamma c)] \text{ cu ft,}$$

$$V_3 = (W_3 \div \gamma s)\text{ ml} = [(W_3) \div (62.29)(\gamma s)] \text{ cu ft,}$$

or
$$V_o = (V) - (V_1 + V_2 + V_3).$$

By definition
$$W = (V)(w_a)$$

and
$$w_t = (W) \div (V_1 + V_2 + V_3).$$

Therefore
$$w_t = (V)(w_a) \div (V - V_o)$$

and
$$(V_o \div V)(100) = [(1) - (w_a \div w_t)]\ (100).$$

The validity of the preceding explanation is based upon the following assumptions: (1) the method of measuring the density of the mortar is fixed, (2) the specific gravity of the sand is the apparent "specific gravity" value of the solid dry aggregate as determined in the Group A Schedule, (3) all mixing water and all other moisture needed to bring the sand to SSD condition are included as W_1 in the equation, and (4) the total volume of all entrained

*Actual weight per unit of volume; also known as unit weight. Refer to end note 4.3 on page 53.

air is V_o. If the sand truly is in an SSD condition at time of mixing, the air content is that within the cement paste because all permeable voids within the sand particles are water-filled; if this is not the case, the quantity of entrained air distributed throughout the mortar cannot be determined. It is apropos to note that cement paste, for the purposes of this discussion, includes whatever bubbles of air may be dispersed throughout the interstices among the particles of sand.

APPENDIX III

PERTINENT DATA FORMS AND WORK SHEETS

Work Sheet WRL-1

VOLUME CHANGE (VCH) OF HARDENED MORTAR WITH AGE
(relative to absolute volume during plastic state)

Sand Identification: GM Rf Mix Water: Sea Brackish Distilled
W/C (by wt): 0. 3 (encircle one)

Mix Number	Entrained Air Content (EAC), % by volume	Plastic State Gross Volume, cc	Solid State Ages →	24 hr	7 days	28 days	91 days	364 days
			Specimen →					
		delete one	(B-C) equiv cc					
		721	less cc air					
			abs vol (solid)					
		734	abs vol (plastic)					
			abs vol diff cc					
			vol change %					
			Specimen →	C 868	C 868	C 869	C 870	C 871
		delete one	(B-C) equiv cc	719	725	720	719	720
		721	less cc air	18	18	18	18	18
			abs vol (solid)	701	707	702	701	702
234	2.5	~~734~~	abs vol (plastic)	703	703	703	703	703
			abs vol diff cc	−2.	+ 4	− 1.	−2.	−1.
			vol change %	− 0.3	+ 0.6	−0.1	− 0.3	−0.1
			Specimen →					
		delete one	(B-C) equiv cc					
		721	less cc air					
			abs vol (solid)					
		734	abs vol (plastic)					
			abs vol diff cc					
			vol change %					
			Specimen →					
		delete one	(B-C) equiv cc					
		721	less cc air					
			abs vol (solid)					
		734	abs vol (plastic)					
			abs vol diff cc					
			vol change %					

NOTE:
1. EAC values are transcribed from appropriate Work Sheet WRL-4.
2. Exact interior volume of individual mold is 733.6 cc and of compartment in gang mold is 721.2 cc.
3. Values of (B-C) are transcribed from appropriate Data Form WRL-13.
4. Values of (B-C) at 24 hr and 7 days are obtained with same specimen; values at 28 days, 91 days, or 364 days are obtained with respective companion specimens.
5. Subtract "abs vol (plastic)" from "abs vol (solid)"; the algebraic sign of "abs vol diff cc" determines shrinkage (-) or swelling (+).

WEIGHT CHANGE (WCH) OF HARDENED MORTAR WITH AGE
(relative to UWP, unit weight during plastic state)

Sand Identification: GM Rf

Mix Water: Sea Brackish Distilled
(encircle one)

W/C (by wt): 0.3

Mix Number: 234

a/UWP: 137.10 pcf

Specimen	*Measured Bulk Density (BUD), pcf, at age					WCH, pcf	d WCH, %
	24 hr	7 days	28 days	91 days	364 days		
----	b/ 137.35	----	----	----	----	c/ at 24 h +0.25	at 24h +0.18
C 868	137.66	138.28	----	----	----	e/ at 7d +1.18	at 7d +0.86
C 869	137.66	----	138.28	----	----	e/ at 28d +1.18	at 28d +0.86
C 870	137.04	----	----	139.53	----	e/ at 91d +2.43	at 91d +1.77
C 871	137.04	----	----	----	140.15	e/ at 364d +3.05	at 364d +2.22
Σ =	549.40	----	----	----	----	----	----
Σ ÷ 4 =	137.35	----	----	----	----	----	----

a Equal to $(W_a)(62.29)$. See Work Sheet WRL-3 for W_a value corresponding to this mix.

b Average 24-hr BUD of all four specimens = (Σ) ÷ (4).

c Average 24-hr BUD less UWP; insert (+) or (-) sign.

d/WCH from plastic to solid state; percentage is relative to UWP value; insert (+) or (-) sign.

e BUD (measured at age shown) less UWP; insert (+) or (-) sign.

* Values transcribed from appropriate Data Form WRL-13.

NOTE: (+) denotes increase and (-) denotes decrease in weight.

Work Sheet WRL-3

PLASTIC MORTAR AIR CONTENT SUMMARY

Mix Number:		*Water:	Sand:	W/C by wt: 0.
	Abs Vol, ml	Wt, gm	γ_s =	
Sand			C/S = , by wt	
Cement				
Water			C/S = , by vol	
Total				
W_c, gm per ml =			$W_a \div W_c$ =	$1-(W_a \div W_c)$ =
W_a, gm per ml =			$[1-(W_a \div W_c)]100$ = % air	

Mix Number:		*Water:	Sand:	W/C, by wt: 0.
	Abs Vol, ml	Wt, gm	γ_s =	
Sand			C/S = , by wt	
Cement				
Water			C/S = , by vol	
Total				
W_c, gm per ml =			$W_a \div W_c$ =	$1-(W_a \div W_c)$ =
W_a, gm per ml =			$[1-(W_a \div W_c)]100$ = % air	

Mix Number: 234		*Water D	Sand: GMRF	W/C, by wt: 0.3
	Abs Vol, ml	Wt, gm	γ_s = 2.72	
Sand	1471	4000	C/S = 1.356, by wt	
Cement	1739	5426		
Water	1732	1732	C/S = 1.182, by vol	
Total	4942	11158		
W_c, gm per ml = 2.258			$W_a \div W_c$ = 0.975	$1-(W_a \div W_c)$ = 0.025
W_a, gm per ml = 2.201			$[1-(W_a \div W_c)]100$ = 2.5 % air	

Mix Number:		*Water	Sand:	W/C, by wt: 0.
	Abs Vol, ml	Wt, gm	γ_s =	
Sand			C/S = , by wt	
Cement				
Water			C/S = , by vol	
Total				
W_c, gm per ml =			$W_a \div W_c$ =	$1-(W_a \div W_c)$ =
W_a, gm per ml =			$[1-(W_a \div W_c)]100$ = % air	

*Insert "S" for sea, "B" for brackish, or "D" for distilled water.
Water specific gravity, at 73±1F temperature: S = 1.023, B = 1.003, D = 1.000.
Cement specific gravity = 3.12.
Sand specific gravity = γs.
Plastic Mortar theoretical unit wt, gm per ml = W_c; computed on this sheet.
Plastic Mortar experimental unit wt, gm per ml = W_a; transcribed from proper Data Form WRL-12.

Work Sheet WRL-4

CORAL MORTAR SUMMARY

Sand Identification: GMRf

Mix Number	*Type Water	W/C, by wt	ΣBUD at 24h, pcf	Flow, %	EAC, % by vol	Age at Test	**BUD, pcf	DYE$\times 10^6$ psi	FLS, psi	MCS, psi
						24h				
						7d				
						28d				
						91d				
						364d				
234	D	0.3	549.40	102	2.5	24h	137.35	—	—	—
						7d	138.28	4.46	1069	6904
						28d	138.28	4.16	1119	9058
						91d	139.53	4.23	1163	8904
						364d	140.15	3.20	988	10025
						24h				
						7d				
						28d				
						91d				
						364d				
						24h				
						7d				
						28d				
						91d				
						364d				

* Insert "S" for sea, "B" for brackish, or "D" for distilled water.

** BUD values transcribed from appropriate Data Form WRL-13 or Work Sheet WRL-2. Value opposite 24h is equal to (ΣBUD) ÷ (4 specimens) or average of entire mix. Values opposite other ages are those for respective singular prisms.

Work Sheet WRL-5

Computations for CMC, YIELD, and A/C of Mortar Mixes

Sand Identification: GMRf W/C: 0.3, by wt Mix Water: Sea Brackish Distilled (encircle one)

ITEM	MIX:	MIX:	MIX:	MIX:	MIX:	MIX:
a = ABS VOL of CEMENT, ml						
b = ABS VOL of MIX, ml						
c = 100(a) ÷ (b), % by vol						
*d = UWP, pcf						
e = CMC, pcf = (c)(d)						
f = YIELD, cfsk = (94) ÷ (e)						
**g = C/S, by wt						
h = A/C, by wt = (1)÷(g)						

ITEM	MIX: 20	MIX: 24	MIX: 233	MIX: 234	MIX: 235	MIX: 236
a = ABS VOL of CEMENT, ml				1739		
b = ABS VOL of MIX, ml				4942		
c = 100(a) ÷ (b), % by vol				35.19		
*d = UWP, pcf				137.10		
e = CMC, pcf = (c)(d)				48.24		
f = YIELD, cfsk = (94) ÷ (e)				1.95		
**g = C/S, by wt				1.356		
h = A/C, by wt = (1) ÷ (g)				0.74		

T = TOTAL QUANTITY of MIXES = 6

av CMC = (SUMMATION of ITEM "e" VALUES) ÷ (T) = (290.11) ÷ (6) = 4835 pcf
av YIELD = (SUMMATION OF ITEM "f" VALUES) ÷ (T) = (11.66) ÷ (6) = 1.94 cfsk
av A/C = (SUMMATION OF ITEM "h" VALUES) ÷ (T) = (4.44) ÷ (6) = 0.74 by wt

*Values of UWP (transcribed from bottom of appropriate Data Form WRL-12) are equal to product of W_a (from appropriate Work Sheet WRL-3) and 62.29 (weight of water, pcf, at 73 F).

**Values of C/S are transcribed from appropriate Work Sheet WRL-3.

Testing Date 30 AUG 1955

Data Form WRL-13 (rev 9 Dec 55)

PHYSICAL PROPERTIES of Hardened Mortar Prisms

Date Cast 23 AUG 1955

Project NY 430 030-9.01

	Temp of Water = 72 F				Temp of Water = 73 F			
Age @ Test	24 Hours				7, 28, 91, 364 (Encircle Age)			
Specimen Identification	C 864	C 868	C 872	C 876	C 864	C 868	C 872	C 876
Test Batch Number	233	234	235	236				
Type of Sand		GMRS						
W/C		0.3						
Density: Wt SSD Prism in Air = (B)		1590				1607		
Density: Wt Bskt + SSD Prism in H_2O = (X + C)		1523				1531		
Density: Wt Bskt in H_2O = (X)		651				649		
Density: Wt SSD Prism in H_2O = (C)		871				882		
Density: (B - C)		719				725		
Density: SSD Bulk Sp Gr of Prism = B ÷ (B - C)		2.21				2.22		
Density: Bulk Density (γ), pcf = 62.29B ÷ (B - C)		137.66				138.28		
FUNDAMENTAL FREQUENCY DATA								
Transverse (n) in cps						225		
Sonic E x 10^6: Short Prisms = $5.48Bn^2$. Long Prisms = $5.73Bn^2$						4.46		
FLEXURAL STRENGTH DATA								
Ctr-Point: Load in lb								
Ctr-Point: Rupture Modulus in psi								
% of Ottawa Mortar Ctr-Point Modulus								
1/3-Point: Load lb						855		
1/3-Point: Rupture Modulus in psi						1069		
% of Ottawa Mortar 1/3-Point Modulus								
COMPRESSIVE STRENGTH DATA								
1 Load lb						28000		
1 Strength psi						7000		
2 Load lb						27750		
2 Strength psi						6937		
3 Load lb						27100		
3 Strength psi						6775		
4 Load lb								
4 Strength psi								
Average Strength in psi						6904		
% of Ottawa Mortar Average Compressive Strength in psi								

Testing Operators Density 1. 2. Frequency ____ Flexural ____ Compressive ____

Ambient Temp- @ Test ____

Testing Date 20 SEPT 1955

Data Form WRL-13 (rev 9 Dec 55)

PHYSICAL PROPERTIES of Hardened Mortar Prisms

Date Cast 23 AUG 1955

Project NY 430 030-9.01

		Temp of Water = 72 F				Temp of Water = 74 F			
Age @ Test		24 Hours				7, 28, 91, 364 (Encircle Age)			
Specimen Identification		C 865	C 869	C 873	C 877	C 865	C 869	C 873	C 877
Test Batch Number		233	234	235	236				
Type of Sand			GMRF						
W/C			0.3						
Density	Wt SSD Prism in Air = (B)		1579				1597		
Density	Wt Bskt + SSD Prism in H_2O = (X + C)		1514				1527		
Density	Wt Bskt in H_2O = (X)		651				650		
Density	Wt SSD Prism in H_2O = (C)		863				877		
Density	(B - C)		716				720		
Density	SSD Bulk Sp Gr of Prism = B ÷ (B - C)		2.21				2.22		
Density	Bulk Density (γ), pcf = 62.29B ÷ (B - C)		137.66				138.28		
FUNDAMENTAL FREQUENCY DATA									
Transverse (n) in cps							218		
Sonic E x 10^6: Short Prisms = $5.48Bn^2$. Long Prisms = $5.73Bn^2$							4.16		
FLEXURAL STRENGTH DATA									
Ctr-Point	Load in lb								
Ctr-Point	Rupture Modulus in psi								
% of Ottawa Mortar Ctr-Point Modulus									
1/3-Point	Load lb						895		
1/3-Point	Rupture Modulus in psi						1119		
% of Ottawa Mortar 1/3-Point Modulus									
COMPRESSIVE STRENGTH DATA									
1	Load lb						37000		
1	Strength psi						9250		
2	Load lb						34800		
2	Strength psi						8700		
3	Load lb						36900		
3	Strength psi						9225		
4	Load lb								
4	Strength psi								
Average Strength in psi							9057		
% of Ottawa Mortar Average Compressive Strength in psi									

Testing Operators Density 1 2. Frequency ______ Flexural ______ Compressive ______

Ambient Temp- @ Test ______

Testing Date 22 NOV 1955

Data Form WRL-13 (rev 9 Dec 55)

PHYSICAL PROPERTIES of Hardened Mortar Prisms

Date Cast 23 AUG 1955

Project NY 430 030-9.01

	Temp of Water = 72 F				Temp of Water = 72 F			
Age @ Test	24 Hours				7, 28, 91, 364 (Encircle Age)			
Specimen Identification	c 866	c 870	c 874	c 878	c 866	c 870	c 874	c 878
Test Batch Number	233	234	235	236				
Type of Sand		GMRf						
W/C		0.3						
Density: Wt SSD Prism in Air = (B)		1579				1608		
Density: Wt Bskt + SSD Prism in H_2O = (X + C)		1511				1542		
Density: Wt Bskt in H_2O = (X)		651				653		
Density: Wt SSD Prism in H_2O = (C)		860				889		
Density: (B - C)		719				719		
Density: SSD Bulk Sp Gr of Prism = B ÷ (B - C)		2.20				2.24		
Density: Bulk Density (γ), pcf = 62.29B ÷ (B - C)		137.04				139.5		
FUNDAMENTAL FREQUENCY DATA								
Transverse (n) in cps						219		
Sonic E x 10^6: Short Prisms = $5.48Bn^2$. Long Prisms = $5.73Bn^2$						4.23		
FLEXURAL STRENGTH DATA								
Ctr-Point: Load in lb								
Ctr-Point: Rupture Modulus in psi								
% of Ottawa Mortar Ctr-Point Modulus								
1/3-Point: Load lb						930		
1/3-Point: Rupture Modulus in psi						1163		
% of Ottawa Mortar 1/3-Point Modulus								
COMPRESSIVE STRENGTH DATA								
1 Load lb						36800		
1 Strength psi						9200		
2 Load lb						34600		
2 Strength psi						8650		
3 Load lb						35450		
3 Strength psi						8862		
4 Load lb								
4 Strength psi								
Average Strength in psi						8904		
% of Ottawa Mortar Average Compressive Strength in psi								

Testing Operators Density 1. 2. Frequency ______ Flexural ______ Compressive ______

Ambient Temp- @ Test ______

Testing Date 21 AUG 1956

Data Form WRL-13 (rev 9 Dec 55)

PHYSICAL PROPERTIES of Hardened Mortar Prisms

Date Cast 23 AUG 1955

Project NY 430 030-9.01

	Temp of Water: 72 F				Temp of Water: 74 F			
Age @ Test	24 Hours				7, 28, 91, 364 (Encircle Age)			
Specimen Identification	C 867	C 871	C 875	C 879	C 867	C 871	C 875	C 879
Test Batch Number	233	234	235	236				
Type of Sand		GMRf						
W/C		0.3						
Density: Wt SSD Prism in Air = (B)		1584				1619		
Density: Wt Bskt + SSD Prism in H_2O = (X + C)		1515				1552		
Density: Wt Bskt in H_2O = (X)		651				653		
Density: Wt SSD Prism in H_2O = (C)		864				899		
Density: (B - C)		720				720		
Density: SSD Bulk Sp Gr of Prism = B ÷ (B - C)		2.20				2.25		
Density: Bulk Density (γ), pcf = 62.29B ÷ (B - C)		137.04				140.15		
FUNDAMENTAL FREQUENCY DATA								
Transverse (n) in cps						190		
Sonic E x 10^6: Short Prisms = $5.48Bn^2$. Long Prisms = $5.73Bn^2$						3.20		
FLEXURAL STRENGTH DATA								
Ctr-Point: Load in lb								
Ctr-Point: Rupture Modulus in psi								
% of Ottawa Mortar Ctr-Point Modulus								
1/3-Point: Load lb						790		
1/3-Point: Rupture Modulus in psi						988		
% of Ottawa Mortar 1/3-Point Modulus								
COMPRESSIVE STRENGTH DATA								
1 Load lb						36900		
1 Strength psi						9225		
2 Load lb						41150		
2 Strength psi						10288		
3 Load lb						42250		
3 Strength psi						10562		
4 Load lb								
4 Strength psi								
Average Strength in psi						10025		
% of Ottawa Mortar Average Compressive Strength in psi								

Testing Operators Density 1. 2. Frequency ______ Flexural ______ Compressive ______

Ambient Temp-
@ Test ______

Data Form WRL-12 (rev 8/58)

PLASTIC-MORTAR MIX DESIGN DATA

Coral-Sand Identification GMRf

Date 23 AUG 1955

Mix Number 234

Project NY 430 030-9.01

Test-Batch Cast at 1330 (USN time)

Operator RBM, HRL, VH

a, Coral-Sand Gradation (encircle one): b, NATURAL; ASTM-GRADED; c, FIELD-MFD; d, LAB HAMMER-CRUSHED; GAP-GRADED; LAB ROLL-CRUSHED

Coral-Sand Condition (encircle one): ROOM-DRY; LAB-WASHED; PRESOAKED; OVEN-DRY

Ottawa-Sand Gradation (encircle one): -20 + 30; -4 + 100

Ottawa-Sand Condition (encircle one): ROOM-DRY PRESOAKED OVEN-DRY

Portland Cement RIVERSIDE Type I (I, II, III, or V)

Mixing Water (encircle one): DISTILLED; DEIONIZED; e, BRACKISH; FRESH; SEA

Identification of specimens made with this mix: C 868 thru C 871

Average room-conditions during fabrication: 78 F at 56 % RH

Consolidation of mortar prisms) 18 Hand-tamped strokes

) — Minutes on vibrating-table at — -inch amplitude

BATCH DATA:

f,	Percent Moisture, by wt	— 2.59
	Quantity Cement, gm	5426
g,	Quantity Sand, gm	4000
	Quantity Water, cc	1732
	Net W/C, by wt	0.3

FLOW DATA:

1st interval	25 1/2
2nd interval	25 3/4
3rd interval	25 3/4
4th interval	25
Average, % of original diameter	102
Average, % of Ottawa value	—

AIR-CONTENT DATA:

Gross wt of 400.0 ml cup filled with mortar, gm	1246.5
Tare of cup, gm	366.2
Net wt of mortar, gm	880.3
UWP, gm per ml = (Net wt mortar) ÷ (400.0 ml)	2.201
UWP, pcf = (UWP, gm per ml) (62.29*)	137.10

a, Use Sheet WRL-5 and Data Form WRL-5A if sieve analysis unavailable; file data with other completed WRL-5A forms.

b, Beach sand or MINUS 4 portion of noncrushed combined coarse-fine.

c, Only MINUS 4 portion of field-crushed combined coarse-fine.

d, Only MINUS 4 portion of resultant combined coarse-fine.

e, 1/6 sea + 5/6 fresh (tap), by volume.

f, Surface moisture of sand denoted by plus (+) sign; absorption of sand denoted by minus (-) sign.

g, Quantity sand used = (Initial wt of selected portion) - (Remaining wt of selected portion).

h, Flow limit = 100 ± 5%.

* **Density of fresh water, pcf, at 73 F temperature.**

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